Effects of Thinning Intensity, Prescribed Fire, and Herbicide on Wildlife Habitat in Mid-rotation Loblolly Pine Stands

by

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Abstract

Pine (*Pinus* spp.) plantations cover 16.8 MM ha across the southeastern United States. Many forest owners are interested in managing their forests for multiple objectives, including timber production and wildlife habitat for both game (e.g., white-tailed deer [*Odocoileus virginianus*]) and nongame species. Commercial thinning and application of herbicide or prescribed fire at mid-rotation can help landowners meet these objectives. However, information is lacking on thinning prescriptions that reduce residual basal area beyond industry standards, as well as the effects of common herbicide tank mixtures (i.e., imazapyr + metsulfuron methyl) on habitat quality for open forest specialists and deer. Therefore, we initiated an operational-scale, manipulative, experiment to quantify the effects of thinning to 9, 14, and 18 m^2 ha^{-1}, with and without prescribed fire and herbicide, on habitat quality for open forest specialists and nutritional carrying capacity (deer days/ha) for deer in mid-rotation loblolly pine stands.

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CHAPTER 1

EFFECTS OF THINNING INTENSITY, PRESCRIBED FIRE, AND HERBICIDE ON UNDERSTORY PLANT COMMUNITIES IN MID-ROTATION LOBLOLLY PINE STANDS

ABSTRACT

Open forests (i.e., woodlands and savannas) are rapidly declining throughout the southeastern United States, due in large part to conversion to pine plantations intensively managed for fiber production. Commercial thinning, prescribed fire, and herbicide are management alternatives that can improve habitat for open forest specialists in pine plantations, but interactions among different levels of thinning, with or without prescribed fire and herbicide, have not been thoroughly evaluated. Therefore, we quantified the effects of thinning, prescribed fire, and herbicide on habitat quality for open forest specialists within five, even-aged loblolly pine (*Pinus taeda*) plantations in central Georgia. We applied a randomized complete block design in which each stand was divided into three equally sized plots, randomly assigned a thinning treatment, and commercially thinned to either 9 (low), 14 (medium), or 18 m^2 ha^{-1} (high) in spring 2017. We applied prescribed fire to half of each plot during spring 2018 and 2020, and herbicide (imazapyr + metsulfuron methyl) to half of each subplot during fall 2019 for a total of 12 treatment combinations. We measured percent coverage and genus richness by growth habit, woody and *Rubus* stem density, and canopy coverage during July–August 2017–2021. Herbaceous cover was generally greater in the low and medium basal area treatments compared to the high basal area treatment. However, herbaceous cover was similar between low and medium basal area treatments, regardless of secondary treatments (fire, herbicide, fire + herbicide), which we attribute to low precision of thinning operations in our stands. Secondary treatments influenced understory vegetation responses more so than thinning intensity throughout the study. Like past studies, we found that herbaceous plant coverage was greater, and the duration of the effect lasted longer, following the second application of fire. The mix treatment, which combined herbicide and prescribed fire, resulted in the greatest coverage of herbaceous plants and the least coverage of vines and woody plants we observed in any treatment combination, two years post-application. Reemergence of understory plants post-herbicide application was faster when fire was also applied. Thus, this treatment may be particularly effective in creating open forest conditions in mid-rotation pine stands with mid- or understories dominated by woody plants. Overall, our results provide information that can be used by managers to develop thinning, prescribed fire, and herbicide prescriptions, depending on focal wildlife species' habitat requirements.

1. INTRODUCTION

Open forests (i.e., woodlands, savannas), characterized by having a semi-open overstory, open midstory, and herbaceous-dominated understory, are rapidly declining throughout the Southeast (Hanberry et al. 2014; Hanberry et al. 2020). For example, fire-mediated shortleaf pine (*Pinus echinata*)-oak (*Quercus* spp.) and longleaf pine (*P. palustris*) woodlands and savannas have declined by 92–96% throughout their historic range (Frost 1993; Oswalt et al. 2012; Oswalt 2013; Hanberry 2021). This decrease was due in large part to increases in loblolly (*Pinus taeda*) and slash (*Pinus elliottii* var. *elliottii*) pine plantations, and fire suppression beginning in the early 1900s (Frost 1993; Brennan et al. 1998; Schultz 1999; Fox et al. 2007; Hanberry 2021). As a result, habitat for both game (e.g., northern bobwhite [*Colinus virginianus*], wild turkey [*Meleagris gallopavo*]) and non-game (e.g., red-cockaded woodpecker [*Picoides borealis*], gopher tortoise [*Gopherus polyphemus*]) species with an affinity for open forests has declined, leading researchers to seek alternative solutions to mitigate habitat loss or restore it (Plentovich et al. 1998; Brawn et al. 2001; Darracq et al. 2016).

Of the estimated 16.8 MM ha of planted pine across the southeastern United States, nearly 13.8 MM ha (82%) consists of loblolly-shortleaf pine (Oswalt et al. 2019). Habitat quality is adequate for many open forest specialists in young, open-canopied stands (Lane et al. 2011; Greene et al. 2016). However, habitat suitability declines precipitously as the stand approaches canopy closure, rebounds after a mid-rotation thin, but eventually declines again as the stand approaches canopy closure later in the rotation (Jones et al. 2009; Jones et al. 2012; Greene et al. 2019*a*; Greene et al. 2019*b*). Greene et al. (2019*a*) also noted that conditions in mid-rotation loblolly pine stands managed for sawtimber were highly ephemeral and tended to occupy the upper range of suitable values for basal area and canopy closure preferred by open forest specialists.

Commercial thinning at mid-rotation increases sunlight availability for understory plant communities, resulting in increased herbaceous plant coverage and plant diversity (Iglay et al. 2006; Campbell et al. 2015). However, without additional disturbance, herbaceous plants are eventually outcompeted and replaced by woody plants, cover increases vertically into the midstory, and the overstory canopy closes (Blair and Enghardt 1976; Blair and Feduccia 1977; Peitz et al. 2001). As such, conditions within thinned stands eventually become unsuitable for open forest specialists.

Accordingly, landowners interested in creating or maintaining open forest conditions conditions in loblolly pine plantations may implement more frequent or intensive thins (Harrington and Edwards 1999; Peitz et al. 1999; Davis et al. 2017). For example, Blair (1967) thinned 29-year-old loblolly pine stands to residual basal areas of 21, 25, and 27 m^2 ha^{-1} and found that herbaceous plant coverage was inversely related to thinning intensity; however, these benefits were greatly diminished by five years post-thin. Peitz et al. (2001) also found that herbaceous coverage in mixed pine-hardwood forests was greatest in stands thinned to the lowest residual basal area (15 m^2 ha^{-1}). Similarly, Cram et al. (2002) found that herbaceous coverage was greater in loblolly pine stands thinned to 15 m^2 ha^{-1} compared to 24 m^2 ha^{-1}. However, thinning intensities in these studies were relatively conservative and represented the upper range of suitable values for basal areas preferred by open forest specialists (Greene et al. 2019*a*).

Although increased thinning intensity promotes herbaceous communities, it also releases woody plants in the understory (Blair and Feduccia 1977). However, prescribed fire and herbicide, applied separately or together, can help prolong the duration of desired vegetation conditions by reducing woody regeneration and promoting herbaceous plants (Iglay et al. 2006; Harper et al. 2016; Greene et al. 2019*b*). For example, Iglay et al. (2014*a*, 2014*b*, 2018) investigated the effects of fire, herbicide (imazapyr), and a combination of fire and herbicide (hereafter, mix) on understory development, avian diversity, and herpetofaunal response in 6, 18–22-year-old loblolly pine stands in Mississippi over a 9-year period. Plant species diversity was greatest in the fire-only treatment units, whereas hardwood midstory control and herbaceous plant coverage were greatest in the mix treatment units, with each treatment benefiting select avian and herpetofaunal species. Overall, they concluded that each alternative was a viable tool for managing open pine systems, each with unique advantages and disadvantages.

However, because of variation in plant susceptibility to various herbicides (e.g., blackberry [*Rubus* spp.] resistance to imazapyr), application of single herbicides may confer a competitive advantage to some plant species versus others, which may reduce species richness (Michael 1987; Iglay et al 2010*b*). Accordingly, some managers have shifted to using tank mixtures (i.e., ≥2 herbicides) at mid-rotation. The most frequently applied herbicide mixture for release treatment in the Southeast is imazapyr (Arsenal® AC) + metsulfuron methyl (Escort®), which is applied to >30,000 ha annually (Shepard et al. 2004). This mixture provides control over a wide array of understory plants, including blackberry, and does not affect loblolly pines (Michael 1987). However, little is known regarding its effects on understory vegetation for wildlife in mid-rotation loblolly pine stands. As a result, many have concerns about the short- and long-term effects of herbicide mixtures on biodiversity, understory composition, successional trajectories, and species richness (Guynn et al. 2004; Miller and Wigley 2004; Shepard et al. 2004).

Forest managers often thin pine plantations to lower residual basal areas (<18 m^2 ha^{-1}) and apply secondary treatments (e.g., prescribed fire, herbicide) at mid-rotation to both create and maintain habitat for open forest specialists. However, to date, none have evaluated the effects of thinning to non-standard residual basal areas, with or without secondary treatments, on understory plant community composition and structure within mid-rotation loblolly pine stands. Additionally, recent studies have noted that imazapyr, an herbicide commonly applied in pine stands to increase habitat quality for open forest specialists, is unable to control well-established native species, which may result in decreased species richness (Iglay et al. 2010*b*). Therefore, we initiated an operational-scale, manipulative experiment to quantify the effects of thinning to 9, 14, and 18 m^2 ha^{-1}, in combination with prescribed fire and herbicide tank mixtures (i.e., imazapyr, metsulfuron methyl), on understory plant community composition and structure within mid-rotation loblolly pine stands. We predicted that (1) understory coverage of all plants would be inversely related to residual basal area, but herbaceous plants would be more sensitive to residual basal area, and (2) herbaceous plant coverage would be greatest in units treated with fire and herbicide two years post-treatment.

2. METHODS AND MATERIALS

2.1. Study sites and design

We conducted research in five, 36–53 ha, loblolly pine plantations within the Piedmont physiographic region of central Georgia. Stands had relatively uniform site indices from 24–25-m (base age 25 years), pre-thinning basal areas from 28–37 $m^2 ha^{-1}$, and were 13–21 years old at study initiation (Colter 2019). Two stands were located within the Georgia Department of Natural Resources' Oconee Wildlife Management Area (WMA) in Greene County, Georgia, USA. The other three were located on property owned and managed by Weyerhaeuser Company in Hancock County, Georgia, USA (*see* Keene et al. 2021*a*, *b*). All stands were historically agricultural sites that had been reforested in loblolly pine and undergone ≥1 loblolly pine rotation. Site preparation for planting included herbicide application and prescribed fire.

The northern pine stand on Oconee WMA had moderately eroded, well-drained soils, with low to medium runoff, comprised of Cecil gravelly and Lloyd gravelly loam, while the southern stand had moderately to severely eroded, well drained soils, with low to high runoff, comprised of Cecil-Cataula complex, Lloyd gravelly loam, and Pacolet sandy loam (Soil Survey 2019). The eastern and western Weyerhaeuser pine stands had moderately eroded, well-drained soils, with low to high runoff, comprised of Cataula-cecil complex and Lloyd gravelly loam, while the northern stand had moderately to excessively well drained soils, very low to very high runoff, comprised of Ailey-Vaucluse-Lucy complex, Fuquay loamy sand, Goldsboro-Noboco complex, Lakeland sand, Vaucluse-Norfolk complex (Soil Survey 2019).

We divided each stand into three evenly sized treatment plots (12–18 ha) and randomly assigned a thinning prescription of 9 (low), 14 (medium), or 18 $m^2 ha^{-1}$ (high). The high residual basal area treatment represents a typical thinning treatment implemented by managers primarily interested in maximizing fiber production by maintaining optimal stocking density, whereas the medium and low basal area treatments represent alternatives available to a landowner primarily interested in improving habitat quality for open pine forest specialists. Each stand was commercially thinned during April–July 2017. Thinned plots were subsequently divided in half (6–9 ha) and each half was randomly assigned a prescribed fire treatment (i.e., fire, no fire), resulting in a split-plot design. We conducted two prescribed burns during the study period, the first during 5 March–3 April 2018 and the second during 15 April–22 April 2020. Prescribed fires were applied to treatment units using a strip-head ignition pattern on days with temperatures ranging from 17–28˚C, 33–59% relative humidity, and wind speeds ≤6 km/hour (Colter 2019; Keene et al. 2021*b*). Flame heights ranged between 0.3–0.6 m and spread at an average rate of 20–40 m/h (Colter 2019). Cost of prescribed burns in the area ranged from 62–124 USD/ha with the average being 86 USD/ha (D. Greene, personal communication).

All subplots were subsequently divided in half (3–5 ha) and randomly assigned an herbicide treatment (i.e., herbicide, no herbicide), ultimately resulting in 12 treatment combinations: fire, no fire, herbicide, and herbicide with fire, across all three basal area treatments. We applied the broadcast herbicide treatment via skidder in September 2019 using a mixture of 0.59 L of Arsenal® AC (imazapyr; BASF Corporation, Research Triangle Park, NC, USA), 0.03 L of Escort® XP (metsulfuron methyl; Bayer CropScience, Cary, NC, USA), and 0.38 L of RRSI Sunset® (methylated seed oil concentrate; Red River Specialties, Inc., Shreveport, LA, USA) per 114 L tank. Cost of herbicide treatments in the area ranged from 106–249 USD/ha with the average being 148 USD/ha (D. Greene, personal communication). Hereafter, we collectively refer to fire, herbicide, and the combination of the two as secondary treatments.

2.2. Plant coverage

We measured understory vegetation response to treatments from July–August 2017–2021. All vegetation metrics were recorded simultaneously along 20-m line transects at a density of 1/0.75 ha. We determined transect points using a two-step approach. First, we overlaid a 50x50 m grid over treatment plots, then randomly selected 5 grid cells per treatment combination to avoid the potential bias associated with overlapping transects and ensure even representation of the treatments (Colter 2019). We oriented transects perpendicular to harvest rows. We measured the horizontal coverage of each plant <2-m tall along the transect and identified them to species or genus when the species could not be determined. If ≥2 species overlapped the same portion of the line transect, we measured each plant (i.e., total coverage could potentially exceed 100%).

We categorized plants *post hoc* into the following groupings by growth habit: grass, forb (legume and non-legume), vine (including *Rubus* spp.), and woody (including shrubs and semi-shrubs). We then calculated percent cover and genus richness by year, treatment, and growth habit.

2.3. Woody stem density

We used the quadrat sampling method to estimate woody and *Rubus* stem density (stems/m^2; Pound and Clements 1898; Colter 2019), which represents interspecific resource competition for the residual pines and the future corresponding midstory. We used the Firemon Cover/Frequency (CF) method of quadrat placement, in which quadrats were systematically placed in set intervals along randomly placed transects (same transects used in line-intercept sampling; Caratti 2006; Colter 2019). We counted and recorded the number and height of all woody stems within two quadrats per transect. Pines (*Pinus* spp.) stems were censored from analyses to avoid potentially inflating woody stem counts in herbicide-treated units (Hu et al. 2012). We grouped stems *post hoc* into two categories: stems ≥1 m in height (i.e., midstory woody stem density) or stems <1 m in height (i.e., understory woody stem density). Stem counts were averaged per transect to produce a singular estimate. In 2020–2021, we modified this method to include all *Rubus* spp. (e.g., highbush blackberry [*Rubus argutus*]) ≥1 m in height (i.e., midstory *Rubus* stem density) as seen previously (Sather and Bradley 2012).

2.4. Canopy closure & visual obstruction

We used a spherical densiometer to estimate total canopy closure ≥1 m in height along each transect (Lemmon 1956). We adapted the Firemon Cover/Frequency (CF) method of quadrat placement, in which quadrats were systematically placed in set intervals along randomly placed transects (same transects used in line-intercept sampling; Caratti 2006; Colter 2019). We took two canopy measurements along each transect at a viewing height of 1 m and averaged them to produce a singular estimate per transect.

We used the cover board method as outlined by Nudds (1977) to estimate visual obstruction ≤2.5 m tall. We recorded the percent of each 0.5-m subsection that was obstructed at a distance of 10 m and a viewing height of 1 m in each cardinal direction per transect. Visual obstruction measurements were averaged per transect to produce a singular estimate.

2.5. Marginal rate of return

We estimated the marginal rate of return (MRR_w) of applying each secondary treatment to reduce woody plant coverage by subtracting the percent cover of vine and woody plants in units treated with each secondary treatment ($NetCoverage_{SecondaryTreatment}$) from the percent cover of vine and woody plants in the untreated controls ($NetCoverage_{Control}$), then dividing the estimate by the set treatment cost ($Cost_{SecondaryTreatment}$). We included data from 2020 and 2021 to estimate

MRR_w for fire, herbicide, and mix treatments. For MRR_w calculations, we pooled percent cover estimates across thinning treatments into a single estimate per secondary treatment per year for ease of interpretation.

$$MRR_W = \frac{NetCoverage_{Control} - NetCoverage_{SecondaryTreatment}}{TreatmentCost_{SecondaryTreatment}}$$

Similarly, we estimated the marginal rate of return (MRR_H) of applying each secondary treatment on herbaceous cover by subtracting the percent cover of herbaceous plants in untreated controls ($NetCoverage_{Control}$) from the percent cover of grasses and forbs (i.e., herbaceous plants) in units treated with each secondary treatment ($NetCoverage_{SecondaryTreatment}$), then dividing the estimate by the set treatment cost ($Cost_{SecondaryTreatment}$). Likewise, we included data from 2020 and 2021 to estimate MRR_H for fire, herbicide, and mix treatments.

$$MRR_H = \frac{NetCoverage_{SecondaryTreatment} - NetCoverage_{Control}}{Cost_{SecondaryTreatment}}$$

2.6. Statistical analysis

We used general linear mixed-effects models (LMMs) within the 'lme4' package (Bates et al. 2015) in R statistical programming (R Core Team 2021) to estimate the effects of thinning intensity, prescribed fire, and herbicide on percent cover and genus richness of plants by year, treatment, and growth habit. We also calculated woody and *Rubus* spp. stem density (stems/m^2), percent canopy closure, and percent visual obstruction by treatment and year. Because treatments were applied in a staggered approach to replicate common silvicultural practices, we used separate analyses to determine the effects of each treatment. Specifically, we used the 2020–2021 data to examine the effects of the herbicide treatment (applied in fall 2019), the 2018–2021 data to examine the effects of prescribed fire (applied in spring 2018 and 2020), and the 2017–2021 data to examine the effects of the thinning treatments (applied in summer 2017). All models included an interactive effect between thinning treatment, secondary treatment (fire, herbicide), and year as in similar studies (Iglay et al. 2010*a*; Iglay et al. 2010*b;* Lashley et al. 2011). As such, models included the response variable, thinning treatment, secondary treatment, and year as interactive, fixed effects, with stand, plot, subplot, subsubplot, and transect id as nested random effects, as appropriate.

Similarly, we used general linear mixed-effects models (LMMs) to estimate the effects of prescribed fire and herbicide on the MRR by year and secondary treatment. We used Akaike's Information Criteria, adjusted for small sample size (AICc), to assess the relative statistical support for each of our three candidate models. Additive and interactive candidate models included the response variable, secondary treatment and year as fixed effects, and the stand as a random effect.

3. RESULTS

3.1. Stand description and composition

We sampled a total of 300, 20-m transects across five stands during July–August 2017–2021. Mean post-thinning basal areas averaged 11 (low), 14 (medium), and 18 m^2 ha^{-1} (high) (Keene et al. 2021*a*). We detected 188 genera (272 identifiable species) of plants including 89 forbs, 49 woody plants, 29 grasses, 17 vines or brambles, 3 ferns, and 1 cactus. The ten most commonly occurring plant genera were *Dichanthelium* spp. (panic grasses), *Rubus* spp. (blackberries), *Vitis* spp. (grapes), *Chasmanthium* spp. (uniolas), *Lespedeza* spp., *Callicarpa* (American beautyberry), *Eupatorium* spp. (bonesets), *Liquidambar* (sweetgum), *Rhus* spp. (sumacs), and *Andropogon* spp. (bluestems & broomsedge, excluding little bluestem). The five most commonly occurring woody genera on stem density surveys were *Pinus* spp. (pines), *Rhus* spp., *Callicarpa*, *Liquidambar*, and *Vaccinium* spp. (blueberries).

3.2. Understory plant response

On average, grass coverage in untreated controls was greater in the low (36%) and medium (34%) basal area units compared to the high (30%) basal area units (Figure 1.1). The five most frequently occurring grass genera were *Dichanthelium* spp., *Chasmanthium* spp., *Andropogon* spp., *Saccharum* spp. (plumegrasses), and *Paspalum* spp. Grass coverage in untreated controls increased annually from 2017 (11%), peaked in 2020 (48%), and declined in 2021 (44%). The year after herbicide application and the second burn (2020), grass coverage was 4% in herbicide plots, 21% in mix plots, and 28% in burned plots. Two years after herbicide application and the second burn (2021), grass coverage was 37% in herbicide plots, 81% in mix plots, and 69% in burn-only plots, compared to 44% in untreated controls.

On average, forb coverage in untreated controls was greater in the low (16%) and medium (18%) basal area units compared to the high (11%) basal area units (Figure 1.1). The five most frequently occurring forb genera were *Lespedeza* spp., *Eupatorium* spp., *Erechtites* (American burnweed), *Senna* (sicklepod), and *Galactia* spp. (milkpeas). Coverage in untreated controls increased annually from 2017 (8%), peaked in 2019 (18%), and declined in 2021 (11%). In 2020, forb coverage was 14% in herbicide plots, 33% in mix plots, and 30% in burned plots. In 2021, forb coverage was 47% in herbicide plots, 79% in mix plots, and 52% in burn-only plots, compared to 11% in untreated controls.

On average, vine & bramble coverage in untreated controls was greater in the low (58%) and medium (55%) basal area units compared to the high (36%) basal area units (Figure 1.1). The five most frequently occurring vine and bramble genera were *Rubus* spp., *Vitis* spp., *Lonicera* (Japanese honeysuckle), *Gelsemium* (Carolina jessamine), and *Smilax* spp. (greenbriers). Coverage in untreated controls increased annually from 2017 (7%) to 2021

(103%). In 2020, vine coverage was 4% in herbicide plots, 5% in mix plots, and 26% in burned plots. In 2021, vine coverage was 31% in herbicide plots, 24% in mix plots, and 50% in burn-only plots, compared to 103% in untreated controls.

Woody coverage in untreated controls was similar among basal area units (Figure 1.1). The five most frequently occurring woody genera were *Callicarpa*, *Liquidambar*, *Rhus* spp., *Vaccinium* spp., and *Pinus* spp. Coverage in untreated controls increased annually from 2017 (10%) to 2021 (67%). In 2020, woody coverage was 3% in herbicide plots, 5% in mix plots, and 20% in burned plots. In 2021, woody coverage was 20% in herbicide plots, 16% in mix plots, and 46% in burn-only plots, compared to 67% in untreated controls.

3.3. Genus richness

Grass, vine, and woody genus richness (genera/20 m transect) were consistent among basal area units. However, forb genus richness was greater in the alternative basal area units (low [6.2 genera]; medium [6.5 genera]) compared to the high basal area units (4.8 genera; Figure 1.2). Herbaceous (i.e., grass and forbs) richness in untreated controls increased annually from 2017 to 2019 then precipitously declined, while vine genus richness stayed consistent among years (4.5 genera) and woody genus richness increased annually (4.2 to 6.3 genera). During 2020 and 2021, grass richness was on average greatest in burn-only (3.6 genera) plots and least in herbicide-only (2.6 genera) and mix (2.8 genera) plots, while forb richness was on average greatest in mix (8.5 genera) plots and least in untreated (4.4 genera) plots. Conversely, vine and woody richness was, on average, greatest in untreated (4.9 genera; 6.0 genera) plots and least in mix (2.3 genera; 2.7 genera) plots, respectively.

3.4. Visual obstruction

Visual obstruction in untreated controls was generally greater in the low and medium basal area units compared to the high basal area units (Figure 1.3). Percent visual obstruction in untreated controls increased annually from 2017 to 2019, then plateaued in 2020 and 2021. During 2020 and 2021, visual obstruction was on average greatest in untreated plots and least in herbicide-only and mix plots.

3.5. Woody stem density

Understory (<1 m in height) woody stem density (stems/m^2) in untreated controls was similar among basal area units (Figure 1.4). Understory woody stem density in untreated controls was static from 2017 to 2021 (~0.6 stems/m^2). During 2020 and 2021, understory woody stem density was, on average, greatest in burn-only (1.0 stems/m^2) and untreated (0.7 stems/m^2) plots and least in herbicide-only (0.3 stems/m^2) and mix (0.4 stems/m^2) plots.

Midstory (≥1 m in height) woody stem density (stems/m^2) in untreated controls was similar among basal area units from 2017 to 2019, then increased in the alternative basal area units compared to the high basal area units from 2020 to 2021 (Figure 1.4). Woody midstory stem density in untreated controls increased annually from 2017 to 2019 (0.1–0.4 stems/m^2), peaked in 2020 (1.1 stems/m^2), and declined in 2021 (0.8 stems/m^2). During 2020 and 2021, woody understory stem density was, on average, greatest in untreated (1.0 stems/m^2) plots and least in herbicide-only (0.1 stems/m^2) and mix (0.1 stems/m^2) plots.

On average, midstory (≥1 m in height) *Rubus* stem density (stems/m^2) in untreated controls was greater in the low (2.7 stems/m^2) and medium (2.0 stems/m^2) basal area units compared to the high (0.6 stems/m^2) basal area units (Figure 1.5). Midstory *Rubus* stem density in untreated controls decreased from 2020 (1.9 stems/m^2) to 2021 (1.6 stems/m^2). During 2020 and 2021, Midstory *Rubus* stem density was, on average, greatest in untreated (1.7 stems/m^2) plots and least in herbicide-only (0.2 stems/m^2) and mix (0.2 stems/m^2) plots.

3.6. Canopy coverage

Canopy coverage (%) was generally greater in high basal area units compared to the low and medium basal area units (Figure 1.6). From 2020 to 2021, canopy coverage in untreated controls increased 9, 9, and 7% in low, medium, and high basal area units, respectively. Canopy coverage was, on average, greatest in untreated (86%) plots and least in mix (77%) plots.

3.7. Marginal rate of return

Our top-ranked models predicting the MRR included an additive effect between secondary treatment and year (Table 1.1). The average cost (USD) to apply prescribed fire, herbicide, and mix (fire + herbicide) treatments was \$86, \$148, and \$234/ha, respectively (D. Greene, personal communication). $\mathrm{MRR_w}$ estimates were similar between years in each secondary treatment unit (Figure 1.7). The year after herbicide application and the second burn (2020), $\mathrm{MRR_w}$ estimates were greater in fire (0.85) and herbicide (0.77) plots and lower in mix (0.50) plots. Two years after herbicide application and the second burn (2021), $\mathrm{MRR_w}$ estimates were greater in fire (0.87) and herbicide (0.79) plots and lower in mix (0.52) plots.

$\mathrm{MRR_H}$ estimates increased from 2020 (-0.15) to 2021 (0.47) across secondary treatment units (Figure 1.7). The year after herbicide application and the second burn (2020), $\mathrm{MRR_H}$ estimates were greater in fire (0.03) plots and lower in herbicide (-0.37) and mix (-0.11) plots. Two years after herbicide application and the second burn (2021), $\mathrm{MRR_H}$ estimates were greater in fire (0.65) and mix (0.51) plots and lower in herbicide (0.25) plots.

4. DISCUSSION

Although grass and forb coverage were generally greater in the low and medium basal area treatments, our hypothesis that herbaceous plant coverage would increase with decreasing basal area was not entirely supported by the data. Specifically, herbaceous cover values were similar between low and medium basal area units, regardless of other (secondary) treatments. Keene et al. (2021*b*) reported similar findings from the first two years post-thinning in our study area, but we expected differences between low and medium basal area units to increase over time. However, given that pine canopy coverage still did not differ between low and medium basal area treatments during the last two years of our study (4–5 years post thinning), this finding is not surprising. We suspect this lack of difference was attributable to low precision of thinning operations in our stands (Keene et al. 2021*a*). Although pre-marking stands prior to thinning increased precision, the increase was relatively minor and likely not justified by the associated costs (Keene et al. 2021*a*). Additionally, open-pine indicator wildlife species are resilient to minor deviations from basal area recommendations (McIntyre et al. 2019). However, managers focused on creating or improving habitat for wildlife that require greater coverage of herbaceous plants than provided in the low and medium basal area units in our study should consider pre-marking stands or consistently monitoring canopy coverage throughout thinning operations to ensure targets are met.

Another unexpected finding was that, although vegetation responses to secondary treatments varied somewhat across basal areas, the effect size of secondary treatments was apparently greater than that for thinning intensity. For example, grass coverage peaked at about 40% in controls, compared to 80% in the mix treatment. Similarly, forb coverage peaked at about 30% in controls, compared to 110% in the mix treatment. While it is evident that the positive effects of thinning on herbaceous coverage would dissipate over time without further disturbance (e.g., Blair 1967), our results also show that herbaceous plant coverage in stands that are only thinned will never reach the levels observed in stands that are also burned or treated with the herbicides we applied and burned.

Previous studies focused on wildlife habitat responses to mid-rotation application of herbicide have generally evaluated broadcast application of imazapyr-only (e.g., Jones and Chamberlain 2004, Gruchy et al. 2009, Iglay et al. 2010*a*, 2010*b*, 2014*b*). Although imazapyr provides effective control of hardwood stems, vines and *Rubus* spp. are unaffected by low rates (BASF Corporation 2012), which may give them a competitive advantage and result in reduced plant diversity. For example, Gruchy et al. (2009) found that bramble coverage doubled following a low-rate application of imazapyr in old fields. Similarly, Jones and Chamberlain (2004) reported vine coverage doubled following an imazapyr treatment in 75–85-year-old mixed pine stands. Additionally, Iglay et al. (2010*a*, 2010*b*) reported that *Rubus* spp. (e.g., highbush blackberry) dominated the understory following an imazapyr treatment in mid-rotation pine stands. In our study, we found that vine coverage was reduced by 95%, and *Rubus* spp. coverage by 94% the first year (2020) post-application, and by 70% and 52%, respectively, in the second year (2021) following application of an imazapyr/metsulfuron methyl mixture.

One concern associated with broadcast application of herbicide in areas managed for wildlife is the period immediately post-application when the area is nearly devoid of plants. This is especially true for herbicide mixtures, which have not been adequately evaluated (Guynn et al. 2004; Miller and Miller 2004). Our data give some credibility to this concern, as percent coverage of all functional groups of plants was least the year following application (2020). However, coverage of grasses and forbs during that year were comparable to stands treated with fire-only. Furthermore, the mix treatment, which combined the herbicide mixture with fire, resulted in the greatest coverage of herbaceous plants we observed in any treatment combination only two years post-application (2021). Previous studies have reported a similar trend in which herbaceous coverage peaks the second year following imazapyr-only and imazapyr + fire treatments (Iglay et al. 2014*b*). However, comparison of effect sizes suggests that our addition of metsulfuron methyl resulted in greater coverage of herbaceous plants compared to imazapyr-only and imazapyr + fire treatments (Iglay et al. 2014*b*), likely due to reduced competition from vines and brambles. As such, combining metsulfuron methyl, imazapyr, and prescribed fire provides excellent control of hardwood stems, vines, and brambles, while maximizing coverage of herbaceous plants, within two growing seasons post-application. Thus, this treatment may be particularly effective in restoring mid-rotation pine stands with mid- or understories dominated by woody plants when managing for wildlife that prefer an herbaceous-dominated understory is an objective (e.g., gopher tortoise; Greene et al. 2019*b*).

Similar to others, we also found that herbaceous plant coverage was greater, and the duration of the effect lasted longer, following the second application of fire. Although forest managers may be discouraged when a single application of prescribed fire fails to produce the desired outcome, repetitive, frequent burns often reduce woody plant coverage while increasing grass and forb coverage (Glitzenstein et al. 2003). Vander Yacht et al. (2020) also reported that herbaceous groundcover, richness, and diversity were greater after repeated burning and that the effect of more intensive thinning on herbaceous plants only became apparent after multiple fire treatments. Outcalt and Brockway (2010) also found that herbaceous plant coverage drastically increased following a second application of prescribed fire.

Prescribed burning cost an average of 86 USD/ha on our study site (D. Greene, personal communication) and 72/ha in other parts of the Southeast (Maggard 2021) and as such represents an affordable tool to both create and maintain open forest conditions. Our data suggest that prescribed fire is a more cost-effective tool for reducing woody vegetation and increasing herbaceous coverage than the most frequently applied tank mixture (i.e., imazapyr + metsulfuron methyl; Shepard et al. 2004) in the southern US. However, forest managers interested in reducing woody plant coverage and increasing herbaceous plant coverage using prescribed fire need to be aware that positive effects may take ≥2 rotations to transpire. Additionally, once dominant vines and woody plants have developed into the midstory, it may be necessary to reset stand succession using a more costly, aggressive treatment option (e.g., mix treatment) before establishing a burn rotation (Edwards et al. 2004; Jones and Chamberlain 2004).

5. SUMMARY AND CONCLUSIONS

Intensive thins (e.g., ≤14 m^2 ha^{-1}) reduced the overstory canopy and invigorated disturbance-dependent plants such as grasses and forbs, which may benefit open forest specialists with an affinity for herbaceous-dominated communities (e.g., gopher tortoise; Greene et al. 2019*b*). However, we found that pine canopy coverage did not differ between low and medium basal area treatments, masking the potential benefits of thinning <14 m^2 ha^{-1} at mid-rotation. We attribute this to low precision of thinning operations in our stands (Keene et al. 2021*a*), and as such recommend forest managers consider pre-marking stands or consistently monitoring canopy coverage throughout thinning operations to ensure targets are met. Additionally, midstory stem density was correlated directly with thinning intensity at mid-rotation and masked the potential benefits of the thinning treatment, reducing habitat suitability for many of these same specialists (e.g., prairie warbler [*Setophaga discolor*]; Engstrom et al. 1984). Prescribed fire was the most cost-effective tool to reduce woody coverage and increase herbaceous coverage, although it may require multiple recurrent applications to achieve the intended result. Once dominant vines and woody plants have developed into the midstory, it may be necessary to reset stand succession before establishing a burn rotation. A combination of metsulfuron methyl, imazapyr, and prescribed fire was the most effective tool at suppressing vine and woody plants, reducing the midstory, and increasing herbaceous plant coverage, which may benefit open forest specialists with an affinity for high herbaceous cover and minimal shrub cover (e.g., Bachman's sparrow [*Peucaea aestivalis*]; McIntyre et al. 2019). As such, we recommend that forest managers interested in maximizing herbaceous coverage and minimizing woody regrowth both thin below the forestry standard (e.g., ≤ 14 m^2 ha^{-1}) and apply prescribed fire and a broadcast application of imazapyr + metsulfuron methyl. However, applying prescribed fire immediately following thinning operations to suppress woody regrowth and maintaining a frequent burn return interval (e.g., 2 years) is the most cost-effective treatment for promoting open forest conditions, benefiting open forest specialists that rely on a mix of herbaceous and semi-woody cover (e.g., northern bobwhite; Greene et al. 2019*a*).

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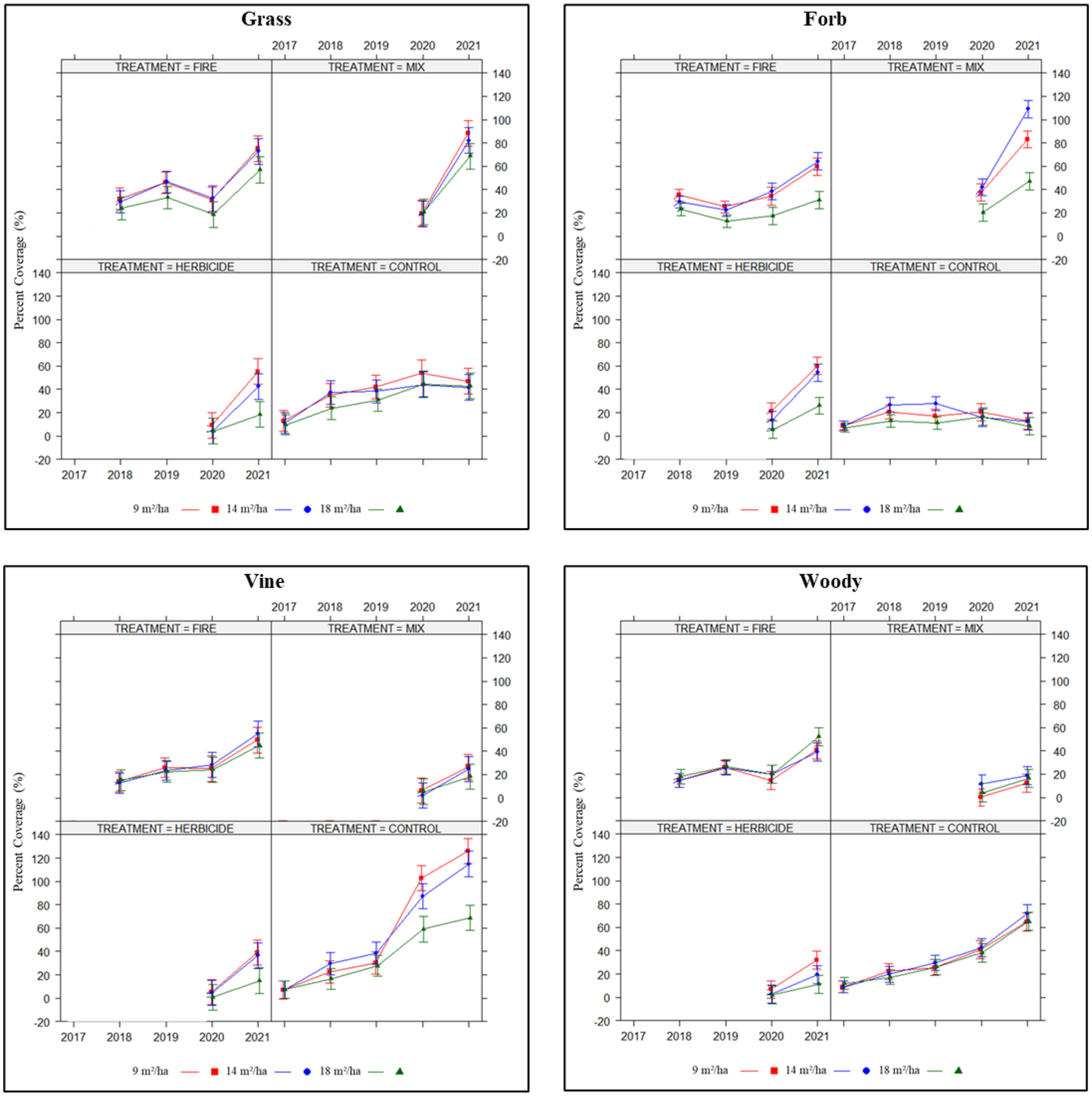


Figure 1.1. Mean estimates of grass, forb, vine, and woody coverage and 95% confidence intervals for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

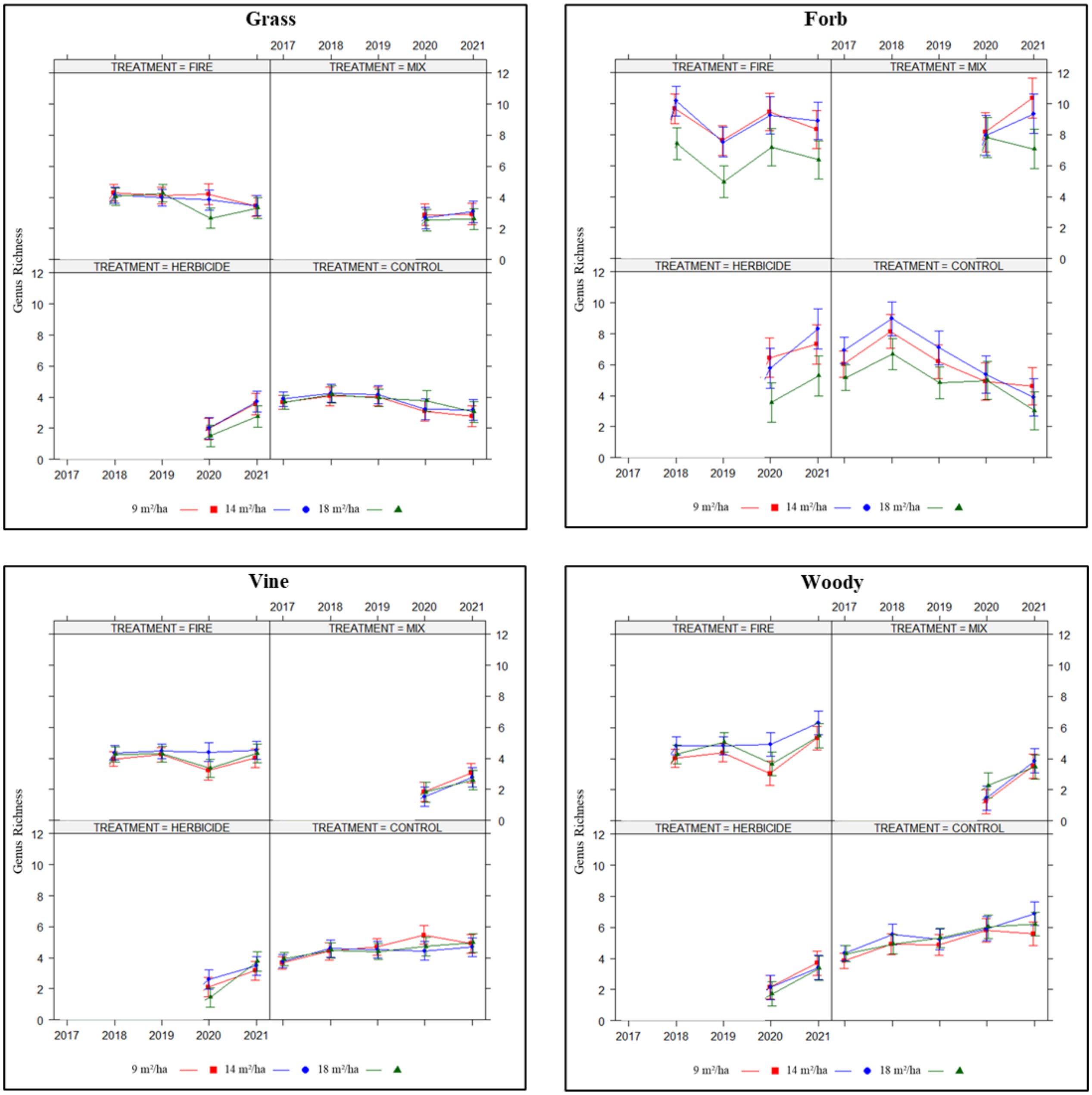
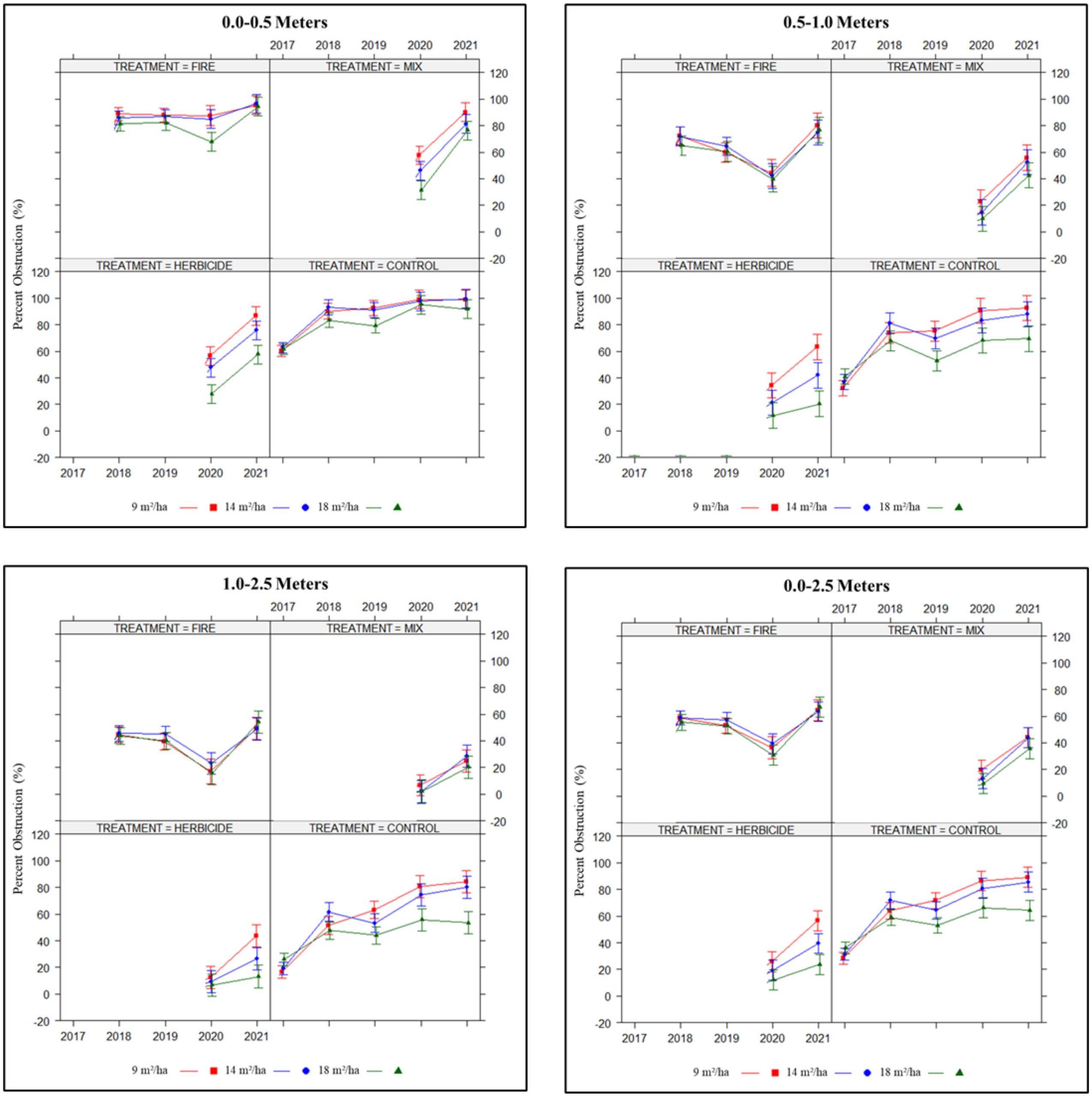


Figure 1.2. Mean estimates of grass, forb, vine, and woody genus richness (genera/20 m transect) and 95% confidence intervals for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.



0.0-0.5 Meters

0.5-1.0 Meters

1.0-2.5 Meters

0.0-2.5 Meters

Figure 1.3. Mean estimates of visual obstruction from 0–0.5 m, 0.5–1.0 m, 1.0–2.5 m, and 0.0–2.5 m in height and 95% confidence intervals for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

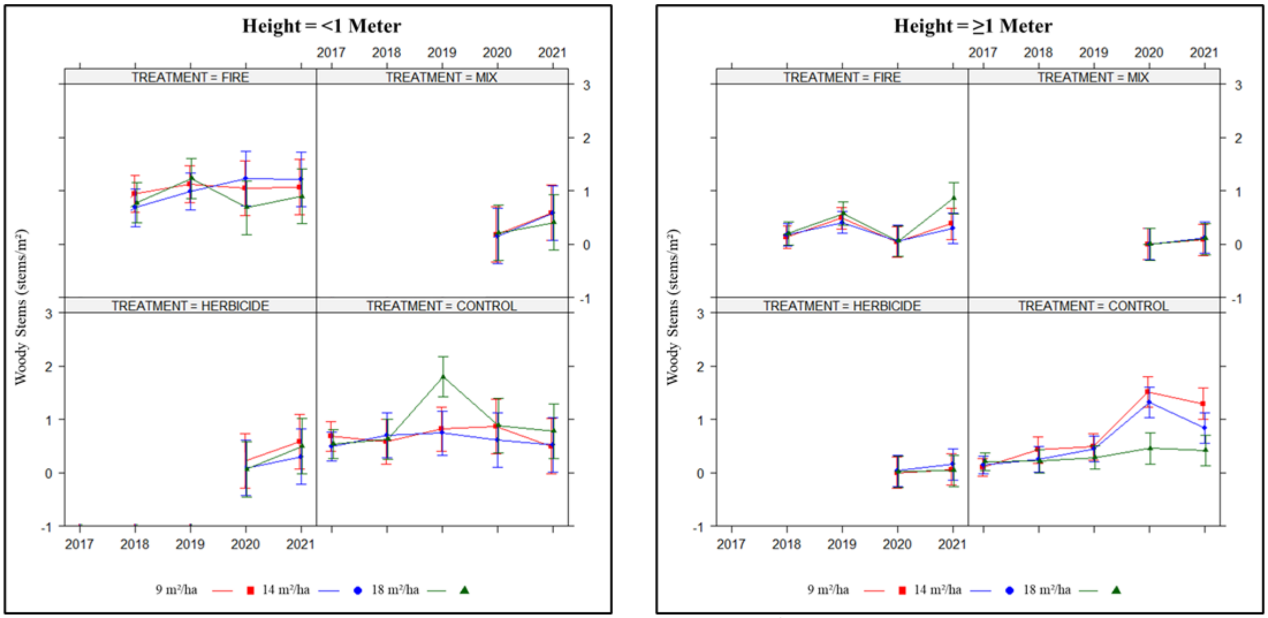


Figure 1.4. Mean estimates of woody stem density (stems/m^2) <1 m and ≥1 m in height and 95% confidence intervals for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

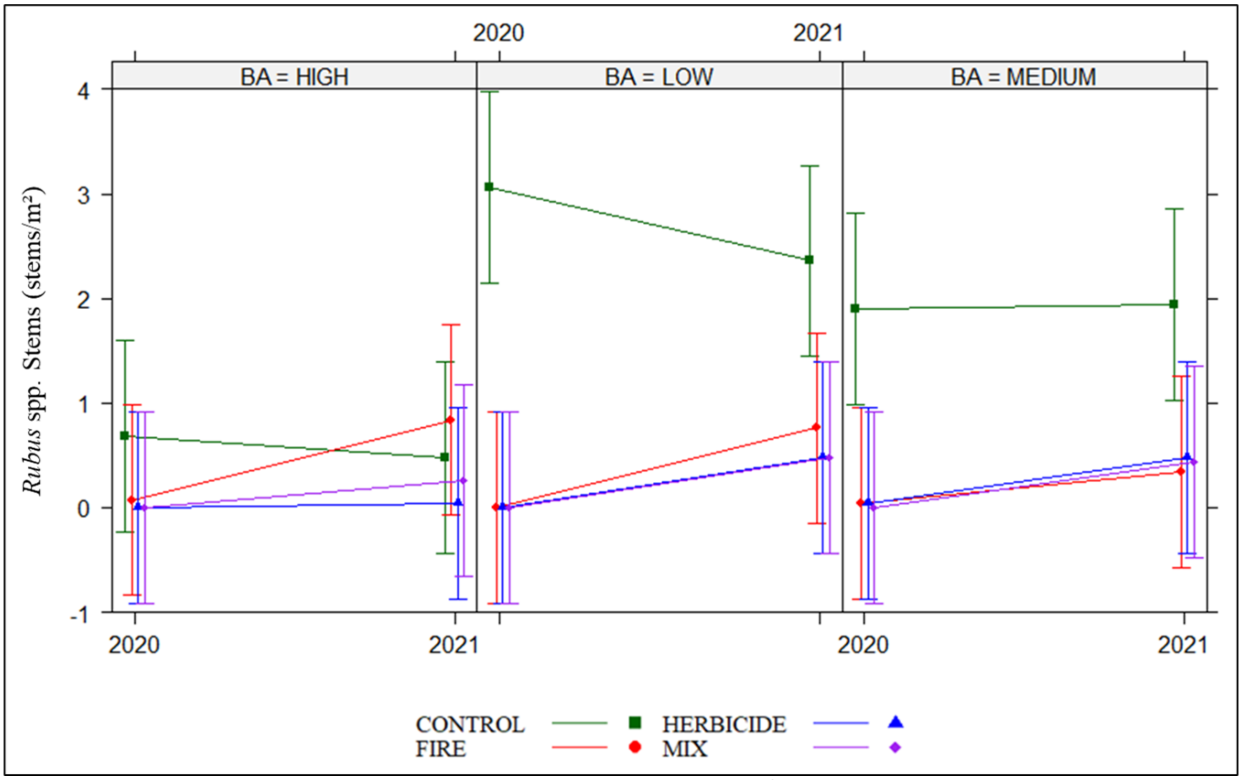


Figure 1.5. Mean estimates of *Rubus* stem density (stems/m^2) ≥1 m in height and 95% confidence intervals for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

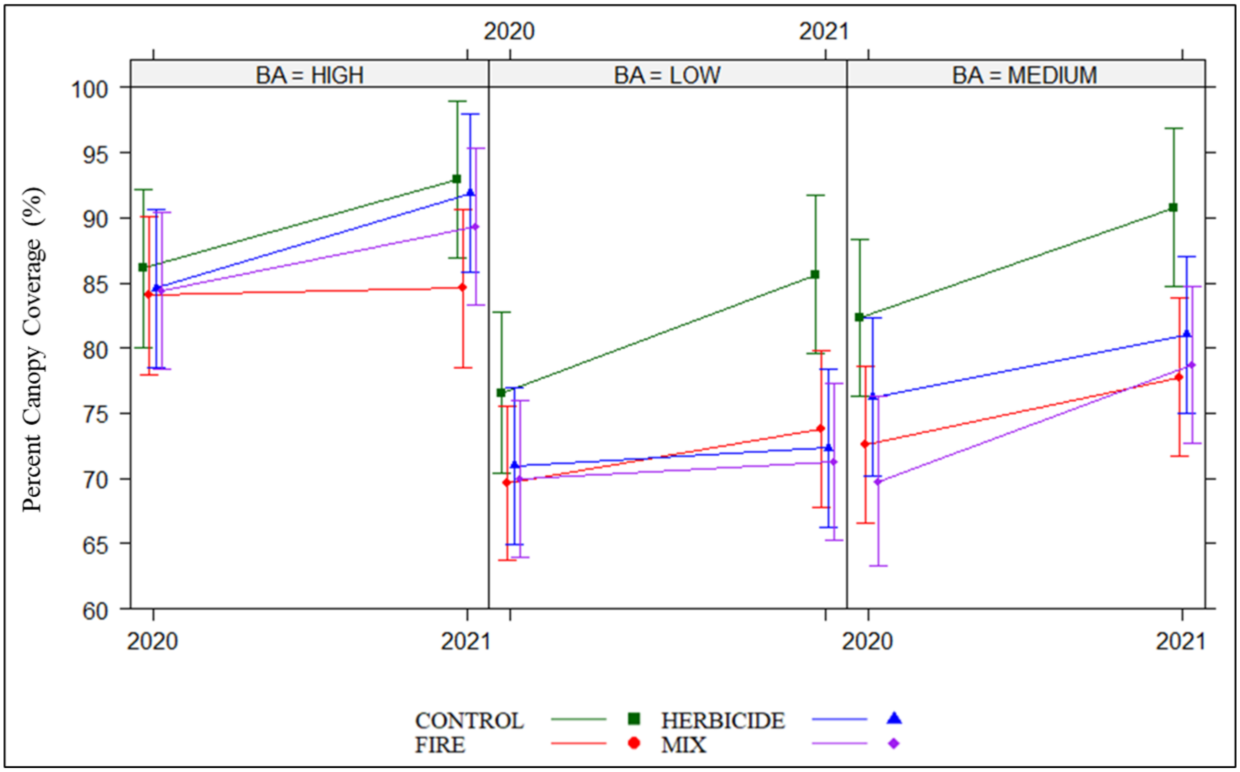


Figure 1.6. Mean estimates of canopy coverage ≥ 1 m in height and 95% confidence intervals for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

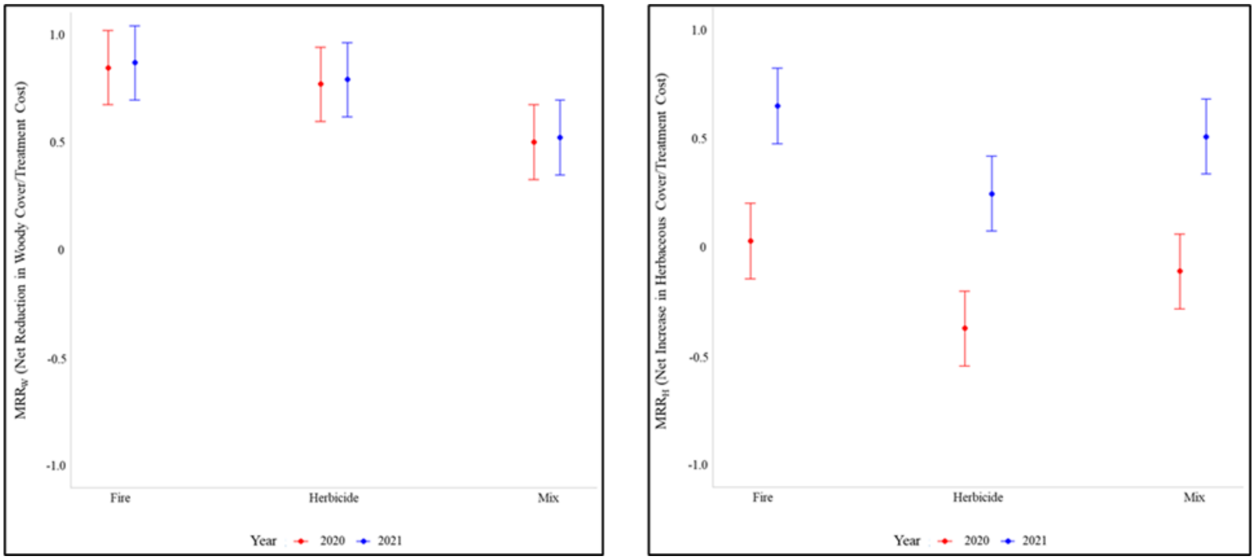


Figure 1.7. Mean marginal rate of return (MRR) estimates of the reduction of woody plants (MRR$_W$) and the increase in herbaceous plants (MRR$_H$) and 95% confidence intervals for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

Table 1.1. Number of parameters (K), Akaike's Information Criterion (AIC_c), difference from lowest AIC_c (ΔAIC_c), and model weights (*w*) for candidate models used to predict the effects of secondary treatments (fire, herbicide, or fire + herbicide) and year on the marginal rate of return (MRR) of the reduction of woody plants (MRR_W) and the increase in herbaceous plants (MRR_H) within mid-rotation loblolly pine stands in Greene and Hancock counties, GA, USA, June 2020–2021.

Candidate Model	***K***	**AIC_c**	**ΔAIC_c**	***W***
Woody plants				
Secondary treatment + year	6	-10.55	0.00	0.96
Secondary treatment * year	8	-4.23	6.32	0.04
Null	3	4.84	15.38	0.00
Herbaceous plants				
Secondary treatment + year	6	9.00	0.00	0.72
Secondary treatment * year	8	10.85	1.85	0.28
Null	3	39.92	30.92	0.00

CHAPTER 2

EFFECTS OF THINNING INTENSITY, PRESCRIBED FIRE, AND HERBICIDE ON NUTRITIONAL CARRYING CAPCITY FOR WHITE-TAILED DEER IN MID-ROTATION LOBLOLLY PINE STANDS

ABSTRACT

Many landowners and managers are interested in improving habitat quality for white-tailed deer (*Odocoileus virginianus*; deer) in loblolly pine (*Pinus taeda*) plantations. Commercial thinning, prescribed fire, and herbicide can increase forage quality and quantity for deer at mid-rotation, but information on deer forage responses to non-traditional thinning prescriptions (i.e., 9 m^2 ha^{-1}) or herbicide mixtures (i.e., imazapyr + metsulfuron methyl), with and without prescribed fire, on nutritional carrying capacity (NCC) for deer is lacking. Therefore, we evaluated the effects of thinning intensity, prescribed fire, and herbicide on forage biomass (kg/ha) and NCC for deer in five loblolly pine plantations in central Georgia, USA. We used a randomized complete block design in which each stand was divided into three equally sized plots and randomly assigned a thinning treatment of 9 (low), 14 (medium), or 18 m^2 ha^{-1} (high). We commercially thinned stands in spring 2017, applied prescribed fire to half of each plot in spring 2018 and 2020, and applied herbicide (imazapyr + metsulfuron methyl) to half of each subplot in fall 2019. We sampled and estimated forage availability and NCC using a 6 (maintenance) and 14% (lactation) crude protein (CP) fixed nutritional constraint in June 2020 and 2021. NCC was greatest in the low basal area treatment but did not differ between the medium and high basal area treatments. Herbicide and fire applied separately or together, reduced vine and woody forage plants, reducing NCC at both nutritional constraints. On average, across years, NCC at 6 and 14% CP constraints was greatest in untreated controls. However, NCC declined from 2020 to 2021 in untreated controls, likely due to additional height growth and maturation of woody plants, suggesting further disturbance is required to maintain NCC at high levels. Accordingly, prescribed fire was the most cost-effective treatment for increasing NCC, and our data suggested disturbance (e.g., thinning, prescribed fire) every 3 years results in the optimal mix of woody plants and forbs, while maintaining plants within reach.

INTRODUCTION

Even-aged pine (*Pinus* spp.) plantations cover >16.8 MM ha across the southern United States and are projected to increase to 21.9 MM ha by 2040 (Wear and Greis 2002; Oswalt et al. 2019). Pine plantation silviculture typically consists of site preparation treatments, seedling planting, one or more mid-rotation thins, and final harvest, usually resulting in a clearcut (Stokes and Watson 1996; Cunningham et al. 2008). Many industrial and non-industrial private forest (NIPF) owners prioritize timber management but derive supplementary income from leasing the hunting rights on these forests. Demand for hunting leases is high due to the widespread privatization of forested lands throughout the Southeast (Butler and Weir 2013; Kant and Alavalapati 2014), creating incentive for forest owners to increase habitat quality for focal game species such as white-tailed deer (*Odocoileus virginianus*; hereafter, deer). In contrast, public land managers and some private forest owners prioritize creating and maintaining habitat for culturally important game species, often at the expense of timber revenue.

Habitat management for deer is centered around maximizing the availability of high-quality forage, particularly when nutritional demands are elevated, such as during lactation or antler growth in early summer (Moen 1978; Hewitt 2011). Forage availability for white-tailed deer is abundant in young, open canopied stands following pine seedling plantings, declines precipitously as the overstory canopy closes, rebounds following mid-rotation thinning, but eventually declines again until disturbance, usually final harvest, increases sunlight availability (Blair and Enghardt 1976; Edwards et al. 2004). Mid-rotation commercial thins increase sunlight availability to the understory, resulting in increased plant diversity and forage availability for deer (Conroy et al. 1982; Jones et al. 2009*a*; Campbell et al. 2015). However, these conditions are highly ephemeral, only lasting for 8–10 years post thin, and diminish as the overstory and midstory canopy closes (Blair 1967; Blair and Enghardt 1976; Greene et al. 2019). Those interested in improving forage availability for deer can implement more intensive or frequent thins (Blair and Enghardt 1976; Peitz et al. 1999). However, these practices will reduce the land expectation value (LEV; Davis et al. 2017), and the positive effect will decrease without periodic application of fire, herbicide, or a combination of both (Blair and Enghardt 1976).

Research has largely described the relationship between deer forage availability and thinning intensity at mid-rotation as a linear relationship (Blair 1967; Blair and Enghardt 1976; Conroy et al. 1982; Peitz et al. 1999; Peitz et al. 2001). For example, Peitz et al. (1999, 2001) thinned loblolly plantations to 15, 18, and 21 m^2 ha^{-1} and found that deer forage production was greatest in the lowest residual basal area treatments. Similarly, Blair and Enghardt (1976) thinned loblolly plantations to 16, 20, 23 m^2 ha^{-1} and reported that forage production and thinning intensity were highly correlated. However, thinning intensities in these studies were relatively conservative ($\geq$15 m^2 ha^{-1}) for those prioritizing wildlife objectives (Bradley and Kush 2019; Moorman and Hamilton 2019), and may not accurately describe the benefits of thinning to lower residual basal areas on nutritional carrying capacity (NCC) for deer.

Hardwoods and semi-woody plants respond to increased sunlight availability following thins and compete with the remaining pines for resources, limiting their potential growth rates

(Bower and Ferguson 1968; D'Anieri et al. 1986; Fortson et al. 1996; Borders and Bailey 2001). Prescribed fire and single herbicides, applied separately or together, can reduce hardwood growth and stem density, increasing sunlight availability, which indirectly increases pine growth and deer forage availability (Jones and Chamberlain 2004; Burke et al. 2008). However, single herbicides may confer a competitive advantage to plants resistant to that herbicide, which may limit pine growth and understory plant species richness (Miller 1991, 1998; Iglay et al 2010*b*; Guynn Jr. et al. 2004). As a result, commercial forest managers have shifted to using tank mixtures (≥2 herbicides) to increase control over a wider spectrum of competing vegetation, decrease costs, or both (Green 1989; Miller 1991, 1998; Shaw and Arnold 2002; Guynn Jr. et al. 2004; Miller and Miller 2004). Imazapyr (Arsenal® AC) + metsulfuron methyl (Escort®) is the most widely applied release tank mixture in the Southeast (Shepard et al. 2004) because it provides extensive control over a wide array of understory plants, including imazapyr-resistant blackberry (*Rubus* spp.) species, yet does not affect pines (Michael 1987; Zutter 1999). However, little is known regarding the effects of this tank mixture, applied with or without prescribed fire, on understory composition and structure. As a result, many are concerned that tank mixtures may temporarily suppress plant growth, decreasing habitat suitability for wildlife such as deer (Guynn et al. 2004; Miller and Miller 2004; Miller and Wigley 2004; Shepard et al. 2004).

To date, none have simultaneously quantified and compared the effects of thinning to non-traditional basal areas in mid-rotation pine plantations, or tested the effects of imazapyr + metsulfuron methyl, applied with and without prescribed fire, on NCC for deer. Therefore, we initiated an operational-scale, spatially replicated experiment to quantify the effects of thinning to 9, 14, and 18 $m^2 ha^{-1}$ in combination with prescribed fire and herbicide (i.e., imazapyr +

metsulfuron methyl) on forage biomass (dry kg/ha) and NCC (deer days/ha) for deer in mid-rotation loblolly pine plantations. We predicted that (1) NCC for deer would be greatest in the lowest basal area treatment (9 m^2 ha^{-1}), (2) NCC for deer at a 6 and 14% crude protein (CP) constraint would be greatest in burned units and least in herbicide treated units due to the wide spectrum of woody plant control.

STUDY AREA

We conducted our research in five, 13–21-year-old, unthinned, planted loblolly pine stands located within the Piedmont physiographic region in central Georgia, USA. Stands were 36–53 ha, had relatively uniform site indices ranging from 24–25-m (base age 25 years), and pre-thinning basal areas ranged from 28–37 m^2 ha^{-1} (Colter 2019). Two stands were in Greene County on Oconee Wildlife Management Area (WMA). The other three were in Hancock County on private property owned and managed by Weyerhaeuser Company. Stands were historically agricultural sites that had been reforested in loblolly pine and undergone ≥1 loblolly pine rotation at project initiation.

The northern loblolly pine stand located on Oconee WMA had moderately eroded, well-drained soils, consisting of Cecil gravelly and Lloyd gravelly loam, with low to medium runoff (Soil Survey 2019). The southern stand had moderately to severely eroded, well drained soils, consisting of Cecil-Cataula complex, Lloyd gravelly loam, and Pacolet sandy loam, with low to high runoff (Soil Survey 2019). The eastern and western pine stand located on Weyerhaeuser property had moderately eroded, well-drained soils, comprised of Cataula-cecil complex and Lloyd gravelly loam, with low to high runoff (Soil Survey 2019). The northern stand had moderately to excessively well drained soils, comprised of Ailey-Vaucluse-Lucy complex, Fuquay loamy sand, Goldsboro-Noboco complex, Lakeland sand, and Vaucluse-Norfolk complex, with very low to very high runoff (Soil Survey 2019).

METHODS

Study Design

We divided each stand into three, equally-sized plots (12–18 ha), randomly assigned a pine thinning prescription of 9 (low), 14 (medium), or 18 $m^2 ha^{-1}$ (high), and commercially thinned each plot during April–July 2017. The high residual basal area treatment represented the industry standard mid-rotation thinning treatment implemented by commercial forest managers primarily focused on maximizing revenue at final harvest by maintaining optional stocking density, whereas the low and medium thinning treatments represent commonly recommended alternatives available to forest managers interested in managing for multiple objectives (e.g., fiber production, deer habitat improvement).

Thinned plots were subsequently divided in half (6–9 ha) and randomly assigned a prescribed fire treatment (fire, no fire). We conducted prescribed burns from 5 March–3 April 2018, with follow-up applications from 15 April–22 April 2020, resulting in a 2-year burn rotation. Prescribed fires were applied using a strip head ignition pattern on days with temperatures ranging from 17–28˚C, 33–59% relative humidity, and wind speeds ≤6 km/hour (Colter 2019; Keene et al. 2021). Flame heights ranged from 0.3–0.6 m, with an average rate of spread from 20–40 m/h (Colter 2019). Cost of prescribed fire treatments in the area ranged from 62–124 USD/ha with the site average being 86 USD/ha (D. Greene, personal communication; Stewart Chapter 1).

Subplots were subdivided in half (3–5 ha) once more and randomly assigned an herbicide treatment (herbicide, no herbicide), creating a split-plot randomized complete block design. We broadcast a mixture of 0.59 L of Arsenal® AC (imazapyr; BASF Corporation, Research Triangle

Park, NC, USA), 0.03 L of Escort® XP (metsulfuron methyl; Bayer CropScience, Cary, NC, USA), and 0.38 L of RRSI Sunset® (methylated seed oil concentrate; Red River Specialties, Inc., Shreveport, LA, USA) per 114 L tank via skidder in September 2019. This resulted in twelve treatment combinations: fire, no fire, herbicide, and herbicide with fire, across all three thinning treatments. Cost to apply herbicide treatments in the area ranged from 106–249 USD/ha with the site average being 148 USD/ha (D. Greene, personal communication; Stewart Chapter 1). Hereafter, we collectively refer to fire treatments, herbicide treatments, and the combination of the two treatments as secondary treatments.

Data Collection & Manipulation

We collected palatable deer forage biomass by randomly distributing five, 1-m^2 quadrats throughout each subplot (n=300) at a density of 1/0.75 ha in June 2020 and 2021. To determine quadrat sampling point locations, we overlaid a 50x50 m grid layer over treatment plots, and randomly selected 5 grid cells per treatment combination to ensure even representation of the treatments (Colter 2019). Forage plants included plants previously noted as browsed in line-intercept surveys conducted the previous year(s), and/or those considered moderate to highly preferred in the literature (Warren and Hurst 1981; Miller and Miller 1999). Palatable growth of each forage plant as defined by Lashley et al. (2014) occurring below the maximum browse height (≤2m; Iglay et al. 2010*a*) and rooted within the quadrat was clipped, bagged separately by genus, labeled, and weighed using a digital scale to the nearest tenth of a gram. We categorized each genus *post hoc* by growth form as a forb (both legumes and non-legumes), vine (including *Rubus* spp.), or woody (including both semi-woody and woody forage plants) plant (Kent et al. 2021). We calculated forage biomass (kg/ha) by year and treatment combination.

Forage samples were dried in industrial scale drying ovens at 50° C and weighed daily until constant mass (≤10% moisture content; Lashley et al. 2014) was recorded for two consecutive days. We packaged and transported forage samples to the Alabama Agricultural Experiment Station at Auburn University (Auburn, AL, USA) for analysis using a wet chemistry nitrogen combustion technique, which is the most accurate nutrient analysis for non-crop forage plants (Lashley et al. 2014). This method of plant tissue analysis is the most accurate method for determining the nitrogen content of non-agricultural plants (Lashley et al. 2014; Nanney et al. 2018). We extrapolated nitrogen (N) values by the conversion factor of 6.25 to estimate the crude protein percent of each forage sample (Robbins 1993).

We estimated nutritional carrying capacity (NCC) in deer days/ha using a mixed-diet approach with fixed crude protein constraints (Hobbs and Swift 1985). The method described by Hobbs and Swift (1985) is predicated on the concept that (1) ungulates are unable to persist on low-quality forages no matter the quantity, and (2) the greater the consumption of high-quality forages the more low-quality forage an ungulate can consume and still meet their nutritional demands. We chose nutritional constraints based on previously reported crude protein requirements for maintenance (6% CP; Asleson et al. 1996; Holter et al. 1979) and peak lactation of a female deer nursing a single fawn (14% CP; Lowell 1984; Jones et al. 2009*b*). We recognize the maintenance value is not adjusted for N losses through skin shedding or digestive and metabolic efficiencies and as such may be an underestimate of the protein threshold necessary for maintaining body condition (Hewitt 2011). Similar to previous studies (Iglay et al. 2010*a*; Lashley et al. 2011; Nanney et al. 2018), we considered crude protein to be the most appropriate nutritional constraint because the difference between maintenance-level and production-level requirements is less variable for digestible energy (2.2 kcal DE/g v. 3.25 kcal DE/g dry matter) as opposed to crude protein (6% v. 14% CP; Jones et al. 2009*b*) in forage plants throughout the

Southeast (Iglay et al. 2010*a*) and has been reported in regional deer feeding studies as a highly selected nutrient (Dykes et al. 2020). Condensed tannins (CT) can reduce plant digestibility, altering nutritional quality of forage plants, however studies in the Southeast have found that the effect of CT on the maximum loss of CP is negligible (Jones et al. 2010). Production-level and maintenance-level forage biomass estimates (kg/ha) were divided by the average dry matter intake rate of a lactating female deer weighing 50 kg (2.4 kg [dry mass]/day; National Research Council 2007) to produce NCC estimates (deer days/ha) per treatment adjusted for nutritional demands (Hobbs and Swift 1985).

We estimated the marginal rate of return ($MRR_{6\%}$) of applying each secondary treatment on nutritional carrying capacity (deer days/ha) for deer by dividing the nutritional carrying capacity at a 6% CP constraint ($NetDeerDays_{SecondaryTreatment}$) by the set treatment cost ($Cost_{SecondaryTreatment}$). NCC mean estimates were pooled across thinning treatments into a single estimate per secondary treatment per year.

$$MRR_{6\%} = \frac{NetDeerDays_{SecondaryTreatment}}{Cost_{SecondaryTreatment}}$$

Similarly, we estimated the marginal rate of return ($MRR_{14\%}$) of applying each secondary treatment on nutritional carrying capacity (deer days/ha) for deer by dividing the nutritional carrying capacity at a 14% CP constraint ($NetDeerDays_{SecondaryTreatment}$) by the set treatment cost ($Cost_{SecondaryTreatment}$). Likewise, NCC mean estimates were pooled across thinning treatments into a single estimate per secondary treatment per year.

$$MRR_{14\%} = \frac{NetDeerDays_{SecondaryTreatment}}{Cost_{SecondaryTreatment}}$$

Data Analysis

We used general linear mixed-effects models (LMMs; Bates et al. 2014) in R statistical programming (R Core Team 2021) to estimate the effect of thinning intensity, prescribed fire, and herbicide on deer forage biomass (kg/ha) and nutritional carrying capacity (deer days/ha) by thinning treatment, secondary treatment, and year. We used Akaike's Information Criteria, adjusted for small sample size (AICc), to evaluate the relative support for each of our seven candidate models. We calculated the differences in least squares means amongst our predicted values using the DIFFLSMEANS function and Kenward–Roger approximation (Lenth 2016). Testing the difference in least square means enabled us to make pair-wise comparisons among combined treatments (e.g., all high basal area treatments). We set an $\alpha=0.05$ for all statistical tests.

Similarly, we used general linear mixed-effects models (LMMs) to estimate the effects of prescribed fire and herbicide, both separately and together, on the MRR by year and secondary treatment. We used Akaike's Information Criteria, adjusted for small sample size (AICc), to assess the respective statistical support for each of our three candidate models. Additive and interactive candidate models included the response variable (MRR), secondary treatment and year as fixed effects, and the stand as a random effect.

RESULTS

Stand Description and Composition

Mean post-thinning basal areas were 11 (low), 14 (medium), and 18 $m^2\ ha^{-1}$ (Keene et al. 2021). We detected 55 deer forage genera (75 identifiable species) of understory plants including 32 forbs, 7 vines, and 16 woody plants (Table 2.1). The ten most commonly occurring deer forage genera were *Rubus* spp. (blackberries), *Callicarpa* (American beautyberry), *Vitis* spp. (grapes), *Rhus* spp. (sumacs), *Lespedeza* spp., *Vaccinium* spp. (blueberries), *Eupatorium* spp. (bonesets), *Smilax* spp. (greenbriers), *Desmodium* spp. (ticktrefoils), and *Toxicodendron* (poison ivy).

Forage Availability

Our top-ranked total biomass (kg/ha) model included a three-way interaction among thinning, secondary treatment, and year (Table 2.2). Comparing differences between least squares means, total biomass was greater in the low basal area treatment compared to the medium and high basal area treatments; however, biomass did not differ between the medium and high basal area treatments (Table 2.3). Total biomass increased between 2020 and 2021 in fire, herbicide, and mix treatment units, yet decreased in untreated controls units. Controls had greater biomass than fire, herbicide, and mix treatment units. Fire treatment units had greater biomass compared to herbicide and mix treatment units, whereas herbicide and mix treatment units did not differ.

Nutritional Carrying Capacity

Our top-ranked model predicting the NCC at a 6% CP constraint included a three-way interaction between thinning treatment, secondary treatment, and year (Table 2.4). Least squares means approximations indicated that NCC at a 6% CP constraint was greater in the low basal area treatment compared to the medium and high basal area treatment yet did not differ between the medium and high basal area treatments (Table 2.5). NCC at a 6% CP constraint increased between 2020 and 2021 in the fire, herbicide, and mix treatment units, yet decreased between years in the untreated control units. NCC at a 6% CP constraint was greater in untreated controls compared to fire, herbicide, and mix treatment units. NCC at a 6% CP constraint was greater in fire treatment units compared to herbicide and mix treatment units, whereas NCC in herbicide and mix treatment units did not differ.

Our top-ranked model predicting NCC at a 14% CP constraint included a three-way interaction between thinning treatment, secondary treatment, and year (Table 2.4). Differences between least squares means indicated that NCC at a 14% CP constraint was greater in the low basal area treatment compared to the medium and high basal area treatments, yet did not differ between the medium and high basal area treatments (Table 2.5). NCC at a 14% CP constraint increased from 2020 to 2021 in the herbicide and mix treatment units, remained constant in the fire treatment units, and decreased in the untreated controls. NCC at a 14% CP constraint was greater in untreated control units compared to fire, herbicide, and mix treatment units, but did not differ among fire, herbicide, and mix treatment units.

Marginal Rate of Return

Our top-ranked candidate models predicting the MRR of nutritional carrying capacity (deer days/ha) at a 6 ($MRR_{6\%}$) and 14% ($MRR_{14\%}$) CP constraint included an additive effect between secondary treatment and year (Table 2.6). Cost (USD) to apply prescribed fire, herbicide, and fire + herbicide treatments averaged $86, $148, and $234/ha, respectively (D. Greene, personal communication; Stewart Chapter 1). $MRR_{6\%}$ estimates increased from 2020 (0.88) to 2021 (1.59) across secondary treatments (Table 2.7). On average, across both years, $MRR_{6\%}$ estimates were greater in fire (3.06) plots and lower in herbicide (0.43) and mix (0.24) plots.

Similarly, $MRR_{14\%}$ estimates increased from 2020 (0.52) to 2021 (0.86) across secondary treatments (Table 2.7). On average, across both years, $MRR_{14\%}$ estimates were greater in fire (1.04) plots and lower in herbicide (0.31) and mix (0.21) plots.

DISCUSSION

Our prediction that NCC would be greater in the low basal area treatment compared to the medium and high basal area treatments was supported by our data. Traditionally, pine plantation managers have considered thinning treatments <14 m^2 ha^{-1} beneficial in promoting grasses (McConnell and Smith 1965), which are of limited forage value to deer in the Southeast (Miller and Miller 1999; Nanney et al. 2018). As such, previous work has largely focused on quantifying the effect of thinning intensity on deer forage availability in pine plantations thinned to ≥15 m^2 ha^{-1} at mid-rotation (Blair 1960, 1967; Blair and Enghardt 1976; Conroy et al. 1982; Peitz et al. 1999; 2001). Though these studies provide useful information to forest managers, they fail to inform those that prioritize maximizing NCC for deer above other objectives. We found that, on average, NCC was 180 deer days/ha greater at the 6% CP constraint and 123 deer days/ha greater at the 14% CP constraint in the low compared to the medium basal area treatment. As such, our data provide the first quantitative evidence that thinning to <14 m^2 ha^{-1} at mid-rotation increases NCC for deer in loblolly pine plantations.

Previous studies on the effects of herbicide on NCC for deer have primarily focused on broadcast applications of imazapyr, with or without prescribed fire (Edwards et al. 2004; Mixon et al. 2009; Iglay et al. 2010*a*). Imazapyr effectively controls woody vegetation, increasing resource availability for protein rich, light-dependent forbs (Jones and Chamberlain 2004, Gruchy et al. 2009, Iglay et al. 2014). However, low-rate imazapyr applications are ineffective in controlling resistant plants such as blackberry, as well as some other well-established species (e.g., American beautyberry [*Callicarpa americana*], grapes; Iglay et al. 2010*a*, 2010*b*), which may outcompete other plants and reduce plant diversity (Iglay et al. 2010*b*). For example, Iglay et al. (2010*a*) reported that highbush blackberry (*R. argutus*) biomass was 2.3 and 3.3 times greater in imazapyr-only and imazapyr + fire treatment units compared to untreated controls. In that study, highbush blackberry was the primary contributor to total biomass and averaged 14.1% CP, driving maintenance (6% CP) and lactation (14% CP) level NCC estimates in both herbicide-only and imazapyr + fire treatment units (Iglay et al. 2010*a*). In our study, blackberries, American beautyberry, and grapes made up 85% of the cumulative biomass collected in untreated control units and were collectively reduced by 92 and 95% in the herbicide and mix treatment units, resulting in reduced NCC estimates at both levels. However, by the second year following herbicide or herbicide + fire treatments (2021), forbs had responded favorably to the reduction in competition (Stewart Chapter 1), and NCC at a 16% constraint (optimal antler development; Harmel et al. 1989) was greater in herbicide and mix treatment units compared to the untreated controls (Figure 2.1).

Prescribed fire is an integral, cost-effective tool used to perpetuate herbaceous plant communities (Masters et al. 1993; Glow and Ditchkoff 2017; Winiarski et al. 2017; Glow et al. 2019), which are of paramount importance to deer in meeting elevated nutritional demands (e.g., lactation, antler growth, body growth) during early summer in the eastern US (Mitchell 1980; McCullough 1985). We found that prescribed fire promoted protein-rich forbs, aided in the recovery of herbaceous plants following herbicide application, and reduced competition from woody plants and vines (Stewart Chapter 1), increasing NCC at higher CP (e.g., 16%) constraints. Mean estimates pooled from data collected in both years (2020, 2021) suggest that NCC at the 16% CP constraint was greater in fire-only treatment units compared to herbicide-only, mix, and untreated controls, and was the most cost-effective secondary treatment. As such, the MRR of applying prescribed fire was far greater than applying herbicide or mix treatments.

Fire frequency is arguably the single most important factor to consider when developing a burn prescription. By altering fire frequency, managers can effectively alter stand succession, composition, and structure, improving habitat suitability for deer (Waldrop et al. 1992; Peterson and Reich 2001; Harper et al. 2016). For example, Glow et al. (2019) found that an annual fire-return interval increased forb and legume biomass, whereas a biennial fire-return interval increased vine and woody biomass. It is widely accepted that a 3–5 yr. fire-return interval will increase forage availability and cover for deer in woodlands (Blair and Feduccia 1977; Lashley et al. 2011; Harper et al. 2016). In agreement, our data indicate that NCC was maximized the fourth year following thinning operations (2020) but decreased the following year (2021) in untreated controls. As such, disturbance (e.g., prescribed fire) every 3–4 years may maximize NCC at maintenance and lactation-levels. However, more frequent disturbance (e.g., prescribed fire) every 1–2 years may increase forb and legume biomass, increasing NCC estimates at higher nutritional constraints.

Fire-excluded or infrequently burned mid-rotation pine plantations often have excess accumulation of vines and woody plants, which hinder ignition and/or fuel consumption, reducing the positive effect of prescribed fire treatments (Waldrop et al. 1992; Iglay et al. 2010*b*). Additionally, high woody stem density may lead to prolific resprouting immediately following a dormant season application of prescribed fire, further negating the positive effects of applying fire (Cram et al. 2009; Harper et al. 2016). Cram et al. (2009) found that woody stem density was ~2 times greater following a dormant season prescribed fire compared to untreated units. Similarly, we found that woody stem density <1 m in height was 46% greater in units treated with prescribed fire compared to untreated controls (Stewart Chapter 1). In contrast, the first year following herbicide application (2020), vine coverage, woody coverage, and woody stem density were reduced by 84–98%. As such, it may be beneficial to apply the imazapyr + metsulfuron methyl mixture we used before implementing a prescribed burn rotation in stands with a significant woody component in the understory (Edwards et al. 2004; Jones and Chamberlain 2004).

Fire, and in particular herbicide with and without fire, can temporarily reduce plant coverage (Guynn Jr. et al. 2004; Miller and Miller 2004; Brockway and Outcalt 2000; Iglay et al. 2014), potentially decreasing NCC for deer. Therefore, treatments separated in time and space can be used to avoid periods where deer forage and/or cover is severely lacking by creating heterogeneity across a managed property (Masters et al. 1993; Masters et al. 1996; Harper et al. 2016). Previous studies have highlighted the benefits of applying multiple secondary treatments (e.g., Iglay et al. 2014), applying the same treatment in different seasons or years (Masters et al. 1996; Harper et al. 2016; Nanney et al. 2018), and burning in a patchwork mosaic (McGranahan et al. 2014; Harper et al. 2016) to create heterogeneity across a property. Manpower, funds, and time-constraints are often the most limiting factors when considering increasing spatiotemporal heterogeneity of plant communities in pine plantations (Harper et al. 2016). However, forest managers unencumbered by these constraints can increase habitat suitability for deer by applying one or more of these practices to increase successional heterogeneity and, by extension, forage and cover throughout the year.

MANAGEMENT IMPLICATIONS

Thinning loblolly pine plantations to 9 m^2 ha^{-1} at mid-rotation increased NCC for deer at levels necessary to support maintenance and lactation. Forest managers primarily focused on maximizing fiber production may avoid this treatment, because it will inevitability decrease the LEV (Davis et al. 2017). However, those that prioritize maximizing NCC for deer above timber objectives can double NCC for deer by reducing stand residual basal from 14 to 9 m^2 ha^{-1} at mid-rotation. However, without additional disturbance, vines and woody plants increase inversely to the residual pine basal area (Blair 1967; Blair and Enghardt 1976; Blair and Feduccia 1977) and develop into the midstory within 3–5 years (Iglay et al. 2010*b*), outcompeting protein-rich forbs and decreasing the amount of forage within a deer’s reach (Lewis and Harshbarger 1976; Plentovich et al. 1998). Repeated application of prescribed fire on a 2–4-year interval is a cost-effective tool to prevent this woody incursion. However, once vines and woody plants have ascended into the midstory, an herbicide application may be necessary before beginning a burn rotation. In that scenario, a combination of imazapyr + metsulfuron methyl is more effective than imazapyr alone in reducing vine and woody plant coverage. As such, we recommend that managers interested in maximizing NCC for deer at higher nutritional constraints (e.g., 16% CP) thin to 9 m^2 ha^{-1} at mid-rotation and immediately begin burning on a 2–4-year fire-return-interval, depending on management objectives.

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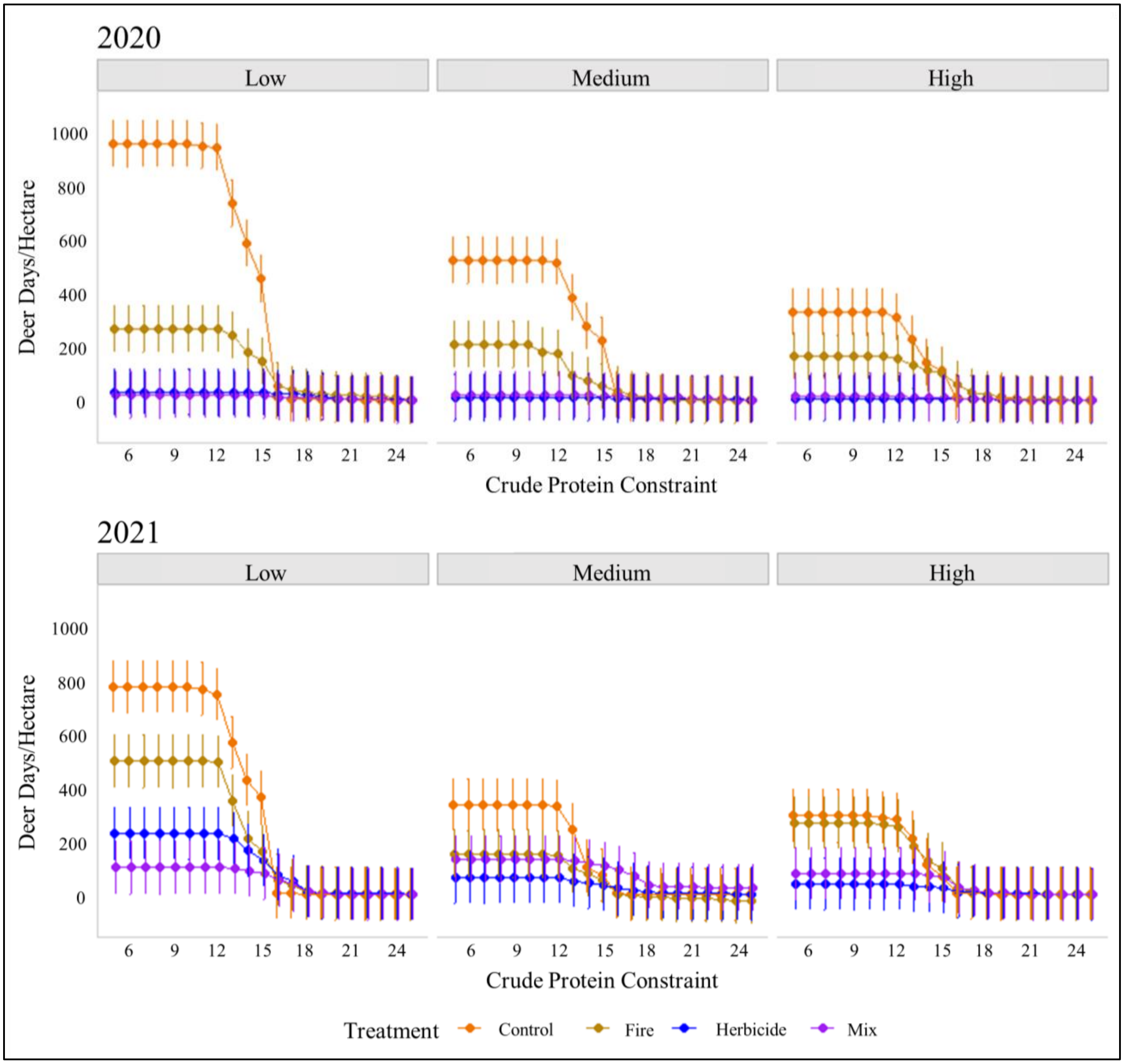

Figure 2.1. Mean estimates of nutritional carrying capacity (deer days/ha) for white-tailed deer (*Odocoileus virginianus*) and 95% confidence intervals across a range of crude protein constraints (5–25) in mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Table 2.1. List of select deer forages occurring ≤2 m in height in mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

Genus[a]	**Common name**	**Species**	**Form**[b]	**Protein**[c] **(%)**
Acalypha	Slender copperleaf	*A. gracilens*	F	15.85
Acer	Florida maple	*A. floridanum*	W	11.91
	Red maple	*A. rubrum*		
Ambrosia	Common ragweed	*A. artemisiifolia*	F	23.40
Aralia	Devil's walkingstick	*A. spinosa*	W	12.10
Aristolochia	Virginia snakeroot	*A. serpentaria*		12.19
Asclepias	Butterfly milkweed	*A. tuberosa*	F	15.38
Aster	White heath aster	*A. pilosus*	F	21.94
Berchemia	Alabama supplejack	*B. scandens*	V	12.79
Bidens	Spanish needles	*B. bipinnata*	F	16.31
Callicarpa	American beautyberry	*C. americana*	W	15.46
Campsis	Trumpetcreeper	*C. radicans*	V	10.83
Centrosema	Spurred butterfly pea	*C. virginianum*	F	23.04
Chamaecrista	Partridge pea	*C. nictitans*	F	20.70
Clitoria	Butterfly pea	*C. mariana*	F	19.63
Cnidoscolus	Bullnettle	*C. stimulosus*	F	26.37
Conyza	Horseweed	*C. canadensis*	F	18.57
Cornus	Flowering dogwood	*C. florida*	W	13.37
Desmodium	Smooth ticktrefoil	*D. laevigatum*	F	16.11
	Stiff ticktrefoil	*D. obtusum*		
	Prostrate ticktrefoil	*D. rotundifolium*		
Elephantopus	Elephantsfoot	*E. tomentosus*	F	13.19
Erigeron	Fleabane	*E.* spp.	F	12.11
Euonymus	Strawberry bush	*E. americana*	W	9.25
Eupatorium	Hyssopleaf thoroughwort	*E. hyssopifolium*	F	17.20
	Late boneset	*E. serotinum*		
Euphorbia	False flowering spurge	*E. pubentissima*	F	13.73
Galactia	Downy milkpea	*G. volubilis*	F	21.08
Galium	Catchweed bedstraw	*G. aparine*	F	11.48
	Fleshy fruit bedstraw	*G. hispidulum*		
Hypericum	St. Andrew's-cross	*H. hypericoides*	W	10.04
	Roundpod St. Johnswort	*H. cistifolium*		
Lespedeza	Bicolor	*L. bicolor*	F	15.41
	Hairy lespedeza	*L. hirta*		
	Creeping lespedeza	*L. repens*		
	Trailing lespedeza	*L. procumbens*		
	Slender lespedeza	*L. virginica*		
Ligustrum	Chinese privet	*L. sinense*	W	15.11

Lonicera	Japanese honeysuckle	*L. japonica*	V	11.54
Morus	Red mulberry	*M. rubra*	W	20.59
Oxalis	Yellow woodsorrel	*O. stricta*	F	18.97
Phytolacca	American pokeweed	*P. americana*	F	24.53
Potentilla	Common cinquefoil	*P. simplex*	F	11.03
Prunus	Black cherry	*P. serotina*	W	11.70
Pycnanthemum	Hoary mountain mint	*P. incanum*	F	11.56
Rhus	Smooth sumac	*R. glabra*	W	11.92
	Winged sumac	*R. copallinum*		
Rosa	Wild rose	*R. carolina*	W	8.56
Rubus	Highbush blackberry	*R. argutus*	V	12.98
	Dewberry	*R.* spp.		
Sabatia	Rose pink	*S. angularis*	F	13.31
Sassafras	Sassafras	*S. albidum*	W	12.25
Smilax	Cat greenbrier	*S. glauca*	V	14.49
	Roundleaf greenbrier	*S. rotundifolia*		
	Saw greenbrier	*S. bona-nox*		
Solanum	American black nightshade	*S. americanum*	F	23.46
	Carolina horsenettle	*S. carolinense*		
Solidago	Canada goldenrod	*S. canadensis*	F	12.27
	Fragrant goldenrod	*S. odora*		
Strophostyles	Trailing fuzzybean	*S. umbellata*	F	19.94
Stylosanthes	Sidebeak pencilflower	*S. biflora*	F	16.67
Tephrosia	Spiked hoary pea	*T. spicata*	F	19.59
Toxicodendron	Poison ivy	*T. radicans*	V	12.12
Tragia	Nettleleaf noseburn	*T. urticifolia*	F	20.84
Trichostema	Forked bluecurls	*T. dichotomum*	F	19.75
Ulmus	Winged elm	*U. alata*	W	14.22
Vaccinium	Deerberry	*V. stamineum*	W	9.78
	Elliott’s blueberry	*V. elliottii*		
	Sparkleberry	*V. arboreum*		
Verbena	Brazilian vervain	*V. brasiliensis*	F	13.89
	Rigid vervain	*V. rigida*		
Viburnum	Rusty blackhaw	*V. rufidulum*	W	9.19
Vitis	Muscadine	*V. rotundifolia*	V	12.22
	Summer grape	*V. aestivalis*		
Wisteria	Chinese wisteria	*W. sinensis*	V	15.38

[a] Genus, common name, and species reported from Miller and Miller (2005) and ITIS.gov.
[b] F, forb; V, vine & bramble; W, woody.
[c] Nitrogen (N) multiplied by the conversion factor of 6.25 (crude protein)

Table 2.2. Number of parameters (K), Akaike's Information Criterion (AIC_c), difference from lowest AIC_c (ΔAIC_c), and model weights (*w*) for candidate models used to predict the effects of thinning intensity, secondary treatments (control, fire, herbicide, or fire + herbicide), and year on total forage availability (kg/ha) for white-tailed deer (*Odocoileus virginianus*) within mid-rotation loblolly pine stands in Greene and Hancock counties, GA, USA, June 2020–2021.

Candidate Model	***K***	**AIC_c**	**ΔAIC_c**	***W***
Thinning intensity * secondary treatment * year	30	9241.19	0.00	1.00
Thinning intensity * secondary treatment	18	9277.12	35.94	0.00
Thinning intensity + secondary treatment + year	13	9282.03	40.84	0.00
Thinning intensity + secondary treatment	12	9284.07	42.89	0.00
Thinning intensity * year	12	9322.94	81.75	0.00
Thinning intensity + year	10	9324.88	83.69	0.00
Null	7	9330.08	88.90	0.00

Table 2.3. Mean estimates ($\bar{x}$), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of total forage available (kg/ha) in mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

	Year[a]							
	2020				**2021**			
Treatment	$\bar{x}$	**SE**	**LCL**	**UCL**	$\bar{x}$	**SE**	**LCL**	**UCL**
High	790	180	436	1144	704	180	350	1057
High + fire	394	180	40	748	639	180	285	992
High + herbicide	14	180	-340	367	93	180	-260	447
High + fire + herbicide	29	173	-311	368	183	176	-162	529
Medium	1251	180	897	1604	802	180	449	1156
Medium + fire	497	181	142	853	411	181	55	767
Medium + herbicide	24	180	-329	378	148	180	-205	502
Medium + fire + herbicide	40	180	-312	392	256	180	-96	607
Low	2301	180	1947	2654	1859	180	1505	2212
Low + fire	641	180	288	995	1191	180	838	1545
Low + herbicide	72	180	-282	425	546	180	193	900
Low + fire + herbicide	48	180	-306	401	236	180	-117	590

[a] Thinning treatment × secondary treatment × year effect ($\Delta AIC_c = 0.00$; $W = 1.00$).

Table 2.4. Number of parameters (K), Akaike's Information Criterion (AIC_c), difference from lowest AIC_c (ΔAIC_c), and model weights (*w*) for candidate models used to predict the effects of thinning intensity, secondary treatments (control, fire, herbicide, or fire + herbicide), and year on nutritional carrying capacity (deer days/ha) for white-tailed deer (*Odocoileus virginianus*) at a 14 and 6% crude protein constraint within mid-rotation loblolly pine stands in Greene and Hancock counties, GA, USA, June 2020–2021.

Candidate Model	***K***	**AIC_c**	**ΔAIC_c**	***W***
6% Crude Protein Constraint				
Thinning intensity * secondary treatment * year	30	8190.28	0.00	1.00
Thinning intensity + secondary treatment + year	18	8226.32	36.04	0.00
Thinning intensity * secondary treatment	13	8231.04	40.75	0.00
Thinning intensity + secondary treatment	12	8233.13	42.85	0.00
Thinning intensity + year	12	8271.40	81.11	0.00
Thinning intensity * year	10	8273.34	83.06	0.00
Null	7	8278.24	87.96	0.00
14% Crude Protein Constraint				
Thinning intensity * secondary treatment * year	30	8248.37	0.00	0.42
Thinning intensity + secondary treatment	12	8249.41	1.04	0.25
Thinning intensity * secondary treatment	18	8249.57	1.20	0.23
Thinning intensity + secondary treatment + year	13	8251.20	2.83	0.10
Thinning intensity + year	10	8264.78	16.40	0.00
Null	7	8265.75	17.38	0.00
Thinning intensity * year	12	8268.49	20.12	0.00

Table 2.5. Mean estimates ($\bar{x}$), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of nutritional carrying capacity (deer days/ha) for white-tailed deer (*Odocoileus virginianus*) at a 14 and 6% crude protein constraint in mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

	Year[a]							
	2020				**2021**			
Treatment	**$\bar{x}$**	**SE**	**LCL**	**UCL**	**$\bar{x}$**	**SE**	**LCL**	**UCL**
6% Crude Protein Constraint								
High	329	76	181	477	293	76	145	441
High + fire	164	76	16	312	266	76	118	414
High + herbicide	6	76	-142	154	39	76	-109	187
High + fire + herbicide	12	76	-136	160	77	76	-71	225
Medium	521	76	373	669	335	76	186	483
Medium + fire	207	76	58	356	171	76	22	320
Medium + herbicide	10	76	-138	158	62	76	-86	210
Medium + fire + herbicide	17	75	-130	164	107	75	-41	254
Low	959	76	811	1107	775	76	627	923
Low + fire	267	76	119	415	497	76	349	645
Low + herbicide	30	76	-118	178	228	76	80	376
Low + fire + herbicide	20	76	-128	168	99	76	-49	247
14% Crude Protein Constraint								
High	141	68	8	274	108	68	-25	241
High + fire	113	68	-20	246	127	68	-6	260
High + herbicide	4	68	-129	137	27	68	-106	160
High + fire + herbicide	9	68	-124	142	70	68	-63	203
Medium	276	68	143	409	102	68	-31	235
Medium + fire	71	68	-63	205	102	68	-32	236
Medium + herbicide	7	68	-126	140	41	68	-92	174
Medium + fire + herbicide	15	67	-117	147	94	67	-38	226
Low	587	68	454	720	425	68	292	558
Low + fire	178	68	45	311	210	68	77	343
Low + herbicide	28	68	-105	161	164	68	31	297
Low + fire + herbicide	17	68	-116	150	85	68	-48	218

[a] Thinning treatment × secondary treatment × year effect (14% CP constraint: $W = 0.42$; 6% CP constraint: $W = 1.00$).

Table 2.6. Number of parameters (K), Akaike's Information Criterion (AIC_c), difference from lowest AIC_c (ΔAIC_c), and model weights (*w*) for candidate models used to predict the effects of secondary treatments (fire, herbicide, or fire + herbicide) and year on the marginal rate of return (MRR) of nutritional carrying capacity (deer days/ha) for white-tailed deer (*Odocoileus virginianus*) at a 6% ($MRR_{6\%}$) and 14% ($MRR_{14\%}$) crude protein constraint within mid-rotation loblolly pine stands in Greene and Hancock counties, GA, USA, June 2020–2021.

Candidate Model	***K***	**AIC_c**	**ΔAIC_c**	***W***
6% Crude Protein Constraint				
Secondary treatment + year	6	91.16	0.00	0.95
Secondary treatment * year	8	96.94	5.78	0.05
Null	3	119.89	28.73	0.00
14% Crude Protein Constraint				
Secondary treatment + year	6	43.41	0.00	0.97
Secondary treatment * year	8	50.38	6.97	0.03
Null	3	74.52	31.11	0.00

Table 2.7. Mean estimates ($\bar{x}$), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of the marginal rate of return (MRR) of nutritional carrying capacity (deer days/ha) for white-tailed deer (*Odocoileus virginianus*) at a 6% ($MRR_{6\%}$) and 14% ($MRR_{14\%}$) crude protein constraint in mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

	Year[a]							
	2020				**2021**			
Treatment	$\bar{x}$	**SE**	**LCL**	**UCL**	$\bar{x}$	**SE**	**LCL**	**UCL**
6% Crude Protein Constraint								
Fire	2.70	0.33	2.06	3.33	3.41	0.33	2.77	4.05
Herbicide	0.07	0.33	-0.57	0.70	0.78	0.33	0.14	1.42
Fire + herbicide	-0.12	0.33	-0.76	0.52	0.59	0.33	-0.05	1.23
14% Crude Protein Constraint								
Fire	1.38	0.15	1.09	1.67	1.73	0.15	1.44	2.01
Herbicide	0.13	0.15	-0.16	0.42	0.48	0.15	0.19	0.77
Fire + herbicide	0.04	0.15	-0.25	0.32	0.38	0.15	0.09	0.67

[a] Secondary treatment + year effect (14% CP constraint: W = 0.97; 6% CP constraint: W = 0.95).

Appendix

Table A1. Understory plants ≤2 m in height occurring in mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020), herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (fire + herbicide; mix) in Greene and Hancock counties, GA.

Genus[a]	**Common name**	**Species**	**Growth form**[b]
Acalypha	Slender copperleaf	*A. gracilens*	F
Acer	Box elder	*A. negundo*	W
	Florida maple	*A. floridanum*	
	Red maple	*A. rubrum*	
Ailanthus	Tree-of-heaven	*A. altissima*	W
Albizia	Mimosa	*A. julibrissin*	W
Ambrosia	Common ragweed	*A. artemisiifolia*	F
Andropogon	Splitbeard bluestem	*A. ternarius*	G
	Broomsedge bluestem	*A. virginicus*	
	Bushy bluestem	*A. glomeratus*	
Antennaria	Pussytoes	*A. spp.*	F
Apium	Wild celery	*A. graveolens*	F
Aralia	Devil’s walkingstick	*A. spinosa*	W
Aristida	Pineland threeawn	*A. stricta*	G
	Purple threeawn	*A. purpurea*	
Arundinaria	Giant cane	*A. gigantea*	G
Asclepias	Butterfly milkweed	*A. tuberosa*	F
	Clasping milkweed	*A. amplexicaulis*	
	Common milkweed	*A. syriaca*	
	White milkweed	*A. variegata*	
Asimina	Smallflower pawpaw	*A. parviflora*	W
	Pawpaw	*A. triloba*	
Asplenium	Ebony spleenwort	*A. platyneuron*	FN
Athyrium	Common ladyfern	*A. filix-femina*	FN
Avenula	Downy oatgrass	*A. pubescens*	G
Baccharis	Eastern baccharis	*B. halimifolia*	W
Berchemia	Alabama supplejack	*B. scandens*	V
Bignonia	Crossvine	*B. capreolata*	V
Callicarpa	American beautyberry	*C. americana*	W
Campsis	Trumpet creeper	*C. radicans*	V
Carpinus	American hornbeam	*C. caroliniana*	W
Carya	Mockernut hickory	*C. tomentosa*	W
	Shagbark hickory	*C. ovata*	
Celtis	Georgia hackberry	*C. tenuifolia*	W
	Sugar hackberry	*C. laevigata*	
Centrosema	Spurred butterfly pea	*C. virginianum*	F
Cercis	Eastern redbud	*Cercis canadensis*	W
Chamaecrista	Partridge pea	*C. nictitans*	F

Chasmanthium	Longleaf uniola	*C. sessiliflorum*	G
	Slender woodoats	*C. laxum*	
Chimphila	Striped prince’s pine	*C. maculata*	F
Cirsium	Thistle	*C. spp.*	F
Clitoria	Butterfly pea	*C. mariana*	F
Cnidoscolus	Bullnettle	*C. texanus*	F
Cocculus	Carolina coralbead	*C. carolinus*	V
Coleataenia	Beaked panicgrass	*C. anceps*	G
Collinsonia	Richweed	*C. canadensis*	F
	Blue Ridge horsebalm	*C. serotina*	
Commelina	Asiatic dayflower	*C. communis*	F
Conyza	Horseweed	*C. canadensis*	F
Coreopsis	Tickseed	*C. spp.*	F
Cornus	Flowering dogwood	*C. florida*	W
Crataegus	Black hawthorn	*C. douglasii*	W
	Parsley hawthorn	*C. marshallii*	
	Yellow hawthorn	*C. flava*	
Croptilon	Scratchdaisy	*C. spp.*	F
Cyperus	Globe flatsedge	*C. echinatus*	G
Danthonia	Poverty oatgrass	*D. spicata*	G
Desmodium	Littleleaf tickclover	*D. ciliare*	F
	Pinebarren ticktrefoil	*D. strictum*	
	Prostrate tickclover	*D. rotundifolium*	
	Smooth tickclover	*D. laevigatum*	
	Stiff ticktrefoil	*D. obtusum*	
Dichanthelium	Needleleaf rosette grass	*D. aciculare*	G
	Variable panic grass	*D. commutatum*	
Digitaria	Crabgrass	*Digitaria spp.*	G
Diodia	Virginia buttonweed	*D. virginiana*	F
Diodella	Poorjoe	*Diodella teres*	F
Dioscorea	Wild yam	*D. villosa*	V
Diospyros	Common persimmon	*D. virginiana*	W
Elaeagnus	Autumn olive	*E. umbellata*	W
Elephantopus	Hairy elephantfoot	*E. tomentosus*	F
Elymus	Eastern bottlebrush grass	*E. hystrix*	G
	Virginia wildrye	*E. virginicus*	
Eragrostis	Bigtop lovegrass	*E. hirsuta*	G
	Purple lovegrass	*E. spectabilis*	
Erechtites	American burnweed	*E. hieraciifolius*	F
Erigeron	Rough fleabane	*E. strigosus*	F
Euonymus	Strawberry bush	*E. americanus*	W
Eupatorium	Dogfennel	*E. capillifolium*	F
	Hyssopleaf thoroughwort	*E. hyssopifolium*	
	Joe-pye-weed	*E. fistulosum*	
	Justiceweed	*E. leucolepis*	
	Late eupatorium	*E. serotinum*	

Euphorbia	False flowering spurge	*E. pubentissima*	F
	Flowering spurge	*E. corollata*	
Euthamia	Slender goldentop	*E. graminifolia*	F
Fagus	American beech	*F. grandifolia*	W
Festuca	Fescue	*F. spp.*	G
Fragaria	Woodland strawberry	*F. vesca*	F
Fraxinus	Green ash	*F. pennsylvanica*	W
	White ash	*F. americana*	
Gaillardia	Gaillardia	*G. aristata*	F
Galactia	Downy milkpea	*G. volubilis*	F
	Eastern milkpea	*G. regularis*	
Galax	Bettleweed	*G. spp.*	F
Galium	Awned bedstraw	*G. aristatum*	F
	Catchweed bedstraw	*G. aparine*	
	Marsh bedstraw	*G. palustre*	
Gelsemium	Carolina jessamine	*G. sempervirens*	V
Geranium	Geranium	*G. spp.*	F
Glandularia	Rose mock vervain	*G. canadensis*	F
Gleditsia	Honeylocust	*G. triacanthos*	W
Hedera	English ivy	*H. helix*	V
Helenium	Bitter sneezeweed	*H. amarum*	F
Hexastylis	Littlebrownjug	*H. arifolia*	F
Hieracium	Hawkweed	*H. spp.*	F
Hypericum	Orangegrass	*H. gentianoides*	W
	Spotted St. johnswort	*H. punctatum*	
	St. Andrew’s cross	*H. hypericoides*	
	Roundpod St. Johnswort	*H. cistifolium*	
	St. Peterswort	*H. crux-andreae*	
Ilex	American holly	*I. opaca*	W
	Yaupon	*I. vomitoria*	
Impatiens	Jewelweed	*I. capensis*	F
Indigofera	True indigo	*I. tinctoria*	W
Ipomoea	Tall morningglory	*I. purpurea*	F
Jacquemontia	Hairy clustervine	*J. tamnifolia*	F
Juncus	Rush	*J. spp.*	G
Juniperus	Eastern red-cedar	*J. virginiana*	W
Kummerowia	Annual lespedeza	*K. spp.*	F
Lactuca	Wild lettuce	*L. canadensis*	F
	Prickly lettuce	*L. serriola*	
Lechea	Hairy pinweed	*L. mucronata*	F
Lepidium	Virginian peppercress	*L. virginicum*	F
Lespedeza	Hairy lespedeza	*L. hirta*	F
	Creeping lespedeza	*L. repens*	
	Trailing lespedeza	*L. procumbens*	
	Slender lespedeza	*L. virginica*	
	Shrubby lespedeza	*L. bicolor*	

	Sericea lespedeza	*L. cuneata*	
Ligustrum	Chinese privet	*L. sinense*	W
Liquidambar	Sweetgum	*L. styraciflua*	W
Liriodendron	Yellow poplar	*L. tulipifera*	W
Lobelia	Great blue lobelia	*L. siphilitica*	F
Lonicera	Japanese honeysuckle	*L. japonica*	V
Ludwigia	Marsh seedbox	*L. palustris*	F
	Bushy seedbox	*L. alternifolia*	
Lygodium	Japanese climbing fern	*L. japonicum*	V
Lyonia	Maleberry	*L. ligustrina*	W
Magnolia	Sweetbay	*M. virgiana*	W
Matelea	Milkvine	*M. spp.*	F
Melia	Chinaberry tree	*M. azedarach*	W
Microstegium	Japanese stiltgrass	*M. vimineum*	G
Mikania	Climbing hempvine	*M. scandens*	V
Mimosa	Sensitive brier	*M. microphylla*	F
Mitchella	Patridgeberry	*M. repens*	V
Monarda	Spotted beebalm	*M. punctata*	F
Morella	Waxmyrtle	*M. cerifera*	W
Morus	Red mulberry	*M. rubra*	W
Muhlenbergia	Nimblewill	*M. schreberi*	G
Nandina	Heavenly bamboo	*N. domestica*	W
Nyssa	Blackgum	*N. sylvatica*	W
Opuntia	Pricklypear	*O. spp.*	C
Ostrya	Eastern hophornbeam	*O. virginiana*	W
Oxalis	Dillen's oxalis	*O. dillenii*	F
	Yellow woodsorrel	*O. stricta*	
Oxydendrum	Sourwood	*O. arboreum*	W
Panicum	Hairy panic grass	*P. hirsutum*	G
	Switchgrass	*P. virgatum*	
Parthenocissus	Virginia creeper	*P. quinquefolia*	V
Paspalum	Bahiagrass	*P. notatum*	G
	Dallis grass	*P. dilatatum*	
	Vaseygrass	*P. urvillei*	
Passiflora	Purple passionflower	*P. incarnata*	F
	Yellow passionflower	*P. lutea*	
Persicaria	Pinweed	*P. pensylvanica*	F
Phyllanthis	Chamber bitter	*P. urinaria*	F
Phytolacca	American pokeweed	*P. americana*	F
Pinus	Loblolly pine	*P. taeda*	W
	Shortleaf pine	*P. echinata*	
Piptochaetium	Blackseed speargrass	*P. avenaceum*	G
Pityopsis	Narrowleaf silkgrass	*P. graminifolia*	F
Plantago	Plantain	*P. spp.*	F
Platanus	American sycamore	*P. occidentalis*	W
Polygonum	Wireweed	*P. erectum*	F

Polypremum	Rustweed	*P. spp.*	F
Polystichum	Christmas fern	*P. acrostichoides*	FN
Portulaca	Kiss-me-quick	*P. pilosa*	F
Potentilla	Oldfield cinquefoil	*P. simplex*	F
Prunus	Black cherry	*P. serotina*	W
	Carolina laurelcherry	*P. caroliniana*	
	Chickasaw plum	*P. angustifolia*	
Pseudognaphalium	Rabbittobacco	*P. obtusifolium*	F
Pueraria	Kudzu	*P. montana*	V
Pycnanthemum	Virginia mountainmint	*P. virginianum*	F
	Hoary mountain mint	*P. incanum*	
Pyrrhopappus	Carolina false dandelion	*P. carolinianus*	F
Quercus	Black oak	*Q. velutina*	W
	Laurel oak	*Q. laurifolia*	
	Post oak	*Q. stellata*	
	Southern red oak	*Q. falcata*	
	Swamp chestnut oak	*Q. michauxii*	
	Water oak	*Q. nigra*	
	White oak	*Q. alba*	
	Willow oak	*Q. phellos*	
Rhamnus	Carolina buckthorn	*R. caroliniana*	W
Rhexia	Meadowbeauty	*R. spp.*	F
Rhus	Smooth sumac	*R. glabra*	W
	Winged sumac	*R. copallinum*	
Rhynchosia	Twining snoutbean	*R. tomentosa*	F
Richardia	Rough Mexican clover	*R. scabra*	F
Robinia	Black locust	*R. pseudoacacia*	W
Rubus	Northern dewberry	*R. flagellaris*	V
	Sawtooth blackberry	*R. argutus*	
	Sand blackberry	*R. cuneifolius*	
Rudbeckia	Blackeyed Susan	*R. hirta*	F
	Cutleaf coneflower	*R. laciniata*	
Ruellia	Fringeleaf wild petunia	*R. humilis*	F
	Wild petunia	*R. nudiflora*	
Sabatia	Rosepink	*S. angularis*	F
Saccharum	Silver plumegrass	*S. alopecuroides*	G
Salvia	Lyreleaf sage	*S. lyrata*	F
Sambucus	Elderberry	*S. spp.*	W
Sanicula	Canadian blacksnakeroot	*S. canadensis*	F
Sassafras	Sassafrass	*S. albidum*	W
Schedonorus	Tall fescue	*S. arundinaceus*	G
Schizachyrium	Little bluestem	*S. scoparium*	G
Scirpus	Woolgrass	*S. cyperinus*	G
Scutellaria	Mad dog skullcap	*S. lateriflora*	F
	Helmet flower	*S. integrifoli*	
Senna	Sicklepod	*S. obtusifolia*	F

Setaria	Bristlegrass	*S. spp.*	G
Silphium	Rosinweed	*S. spp.*	F
Smallanthus	Hairy leafcup	*S. uvedalia*	F
Smilax	Laurel greenbrier	*S. laurifolia*	V
	Cat greenbrier	*S. glauca*	
	Lanceleaf greenbrier	*S. smallii*	
	Roundleaf greenbrier	*S. rotundifolia*	
	Saw greenbrier	*S. bona-nox*	
Solanum	Smallflower nightshade	*S. americanum*	F
	Carolina horsenettle	*S. carolinense*	
Solidago	Canada goldenrod	*S. canadensis*	F
	Fragrant goldenrod	*S. odora*	
	Showy goldenrod	*S. speciosa*	
Sorghastrum	Yellow indian-grass	*S. nutans*	G
Sorghum	Johnsongrass	*S. halepense*	G
Steinchisma	Lax panicgrass	*S. laxa*	G
Strophostyles	Trailing fuzzy-bean	*S. helvola*	F
	Perennial wildbean	*S. umbellata*	
Stylosanthes	Sidebeak pencilflower	*S. biflora*	F
Styrax	American snowbell	*S. americanus*	W
Talinum	Verdolaga-Francesa	*T. fruticosum*	F
Taraxacum	Dandelion	*T. spp.*	F
Tephrosia	Hoarypea	*T. sinapou*	F
	Spiked hoarypea	*T. spicata*	
Toxicodendron	Eastern poison ivy	*T. radicans*	W
	Atlantic poison oak	*T. pubescens*	
Tragia	Nettleleaf noseburn	*Tragia urticifolia*	F
	Branched noseburn	*T. ramosa*	
Trichostema	Forked bluecurls	*T. dichotomum*	F
Tridens	Purpletop tridens	*T. flavus*	G
Tripsacum	Eastern gamagrass	*T. dactyloides*	G
Ulmus	American elm	*U. americana*	W
	Slippery elm	*U. rubra*	
	Winged elm	*U. alata*	
Vaccinium	Blue Ridge blueberry	*V. pallidum*	W
	Deerberry	*V. stamineum*	
	Elliott's blueberry	*V. elliottii*	
	Sparkleberry	*V. arboreum*	
Verbascum	Common mullein	*V. thapsus*	F
Verbena	Brazilian vervain	*V. brasiliensis*	F
	Tuberous vervain	*V. rigida*	
Vernonia	Ironweed	*V. spp.*	F
Vibernum	Possumhaw	*V. nudum*	W
	Rusty blackhaw	*V. rufidulum*	
Vicia	Vetch	*V. spp.*	F
Viola	Violet	*V. spp.*	F

Vitis	Muscadine	*V. rotundifolia*	V
	Summer grape	*V. aestivalis*	V
Wahlenbergia	Southern rockbell	*W. marginata*	F
Wisteria	Chinese wisteria	*W. sinensis*	V

[a] Genus, common name, and species reported from Miller and Miller (2005) and ITIS.gov.

[b] C, cacti; FN, fern; F, forb, rush, sedge; G, grass; V, vine & bramble; W, woody.

Table A2. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of grass coverage (%) for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA

Model	**Year**	**Basal Area**	**Treatment**	**β**	**SE**	**LCL**	**UCL**
All treatments	2020	High	Control	46.18	8.29	29.93	62.44
			Herbicide	2.32	8.29	-13.94	18.57
			Fire	19.74	8.26	3.55	35.93
			Mix	19.79	8.34	3.45	36.13
		Medium	Control	43.23	8.29	26.97	59.49
			Herbicide	3.03	8.29	-13.23	19.29
			Fire	32.07	8.29	15.81	48.33
			Mix	21.36	8.29	5.10	37.61
		Low	Control	52.99	8.29	36.73	69.24
			Herbicide	7.19	8.26	-9.00	23.38
			Fire	31.62	8.34	15.28	47.96
			Mix	21.51	8.29	5.25	37.76
	2021	High	Control	44.24	8.29	27.93	62.44
			Herbicide	16.44	8.29	0.19	32.70
			Fire	58.14	8.29	41.89	74.40
			Mix	67.84	8.29	51.59	84.10
		Medium	Control	40.88	8.29	24.62	57.13
			Herbicide	41.32	8.29	25.07	57.58
			Fire	72.48	8.29	56.23	88.74
			Mix	84.25	8.29	67.99	100.50
		Low	Control	45.95	8.29	29.69	62.20
			Herbicide	53.93	8.29	37.67	70.18
			Fire	75.84	8.29	15.28	47.96
			Mix	90.19	8.29	73.94	106.45
Fire	2018	High	Fire	24.11	5.78	12.77	35.44
		Medium	Fire	29.84	5.51	19.03	40.65
		Low	Fire	31.42	5.51	20.61	42.23
	2019	High	Fire	33.34	5.78	22.00	44.67
		Medium	Fire	47.00	5.53	36.16	57.85
		Low	Fire	45.23	5.52	34.40	56.05
	2020	High	Fire	18.82	6.52	6.05	31.60
		Medium	Fire	32.09	6.46	19.43	44.76
		Low	Fire	30.17	6.51	17.41	42.93
	2021	High	Fire	57.25	6.56	44.38	70.11
		Medium	Fire	72.50	6.46	59.84	85.17
		Low	Fire	74.28	6.46	61.61	86.95
Thinning intensity	2017	High	Control	9.52	4.42	0.86	18.19
		Medium	Control	11.24	4.43	2.56	19.92
		Low	Control	12.84	4.43	4.17	21.51

2018	High	Control	23.93	4.83	14.46	33.39
	Medium	Control	34.81	5.02	24.96	44.66
	Low	Control	32.84	5.02	22.99	42.68
2019	High	Control	30.91	4.83	21.45	40.37
	Medium	Control	35.98	4.99	26.20	45.77
	Low	Control	39.74	5.01	29.92	49.55
2020	High	Control	44.67	5.41	34.07	55.26
	Medium	Control	44.26	5.42	33.64	54.89
	Low	Control	54.32	5.42	43.70	64.95
2021	High	Control	42.73	5.41	32.14	53.33
	Medium	Control	41.92	5.42	31.29	52.55
	Low	Control	47.28	5.42	36.66	57.91

Table A3. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of forb coverage (%) for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	**Year**	**Basal Area**	**Treatment**	**β**	**SE**	**LCL**	**UCL**
All treatments	2020	High	Control	17.51	6.47	4.82	30.20
			Herbicide	4.40	6.47	-8.29	17.09
			Fire	17.70	6.43	5.09	30.30
			Mix	19.93	6.53	7.14	32.73
		Medium	Control	16.12	6.47	3.43	28.81
			Herbicide	13.00	6.47	0.31	25.69
			Fire	38.02	6.47	25.33	50.71
			Mix	42.71	6.47	30.02	55.40
		Low	Control	19.76	6.47	7.07	32.45
			Herbicide	23.04	6.43	10.44	35.65
			Fire	34.83	6.53	22.04	47.63
			Mix	35.52	6.47	22.83	48.21
	2021	High	Control	9.17	6.47	-3.52	21.86
			Herbicide	25.01	6.47	12.32	37.70
			Fire	31.22	6.47	18.53	43.91
			Mix	47.14	6.47	34.45	59.83
		Medium	Control	12.63	6.47	-0.06	25.32
			Herbicide	53.53	6.47	40.84	66.22
			Fire	63.79	6.47	51.10	76.48
			Mix	109.81	6.47	97.12	122.50
		Low	Control	12.26	6.47	-0.43	24.95
			Herbicide	62.00	6.47	49.31	74.69
			Fire	60.35	6.47	47.66	73.04
			Mix	81.31	6.47	68.62	94.00
Fire	2018	High	Fire	23.21	3.80	15.77	30.66
		Medium	Fire	29.99	3.46	23.22	36.76
		Low	Fire	35.33	3.46	28.56	42.11
	2019	High	Fire	13.14	3.80	5.69	20.59
		Medium	Fire	22.84	3.48	16.02	29.66
		Low	Fire	25.20	3.47	18.41	32.00
	2020	High	Fire	17.51	4.60	8.49	26.53
		Medium	Fire	38.66	4.52	29.79	47.53
		Low	Fire	35.00	4.58	26.02	43.97
	2021	High	Fire	31.20	4.65	22.08	40.31
		Medium	Fire	64.31	4.53	55.43	73.19
		Low	Fire	60.71	4.53	51.83	69.60
Thinning intensity	2017	High	Control	7.13	1.58	4.04	10.21
		Medium	Control	8.88	1.58	5.78	11.98
		Low	Control	8.80	1.58	5.71	11.90

2018	High	Control	12.93	1.99	9.03	16.83
	Medium	Control	25.53	2.18	21.25	29.81
	Low	Control	20.97	2.18	16.69	25.25
2019	High	Control	11.03	1.99	7.13	14.94
	Medium	Control	26.28	2.15	22.06	30.49
	Low	Control	17.08	2.17	12.84	21.33
2020	High	Control	16.70	2.54	11.71	21.69
	Medium	Control	16.03	2.55	11.03	21.03
	Low	Control	20.87	2.55	15.87	25.87
2021	High	Control	8.47	2.55	3.48	13.46
	Medium	Control	12.48	2.56	7.46	17.49
	Low	Control	13.26	2.55	8.25	18.26

Table A4. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of vine coverage (%) for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	58.38	9.87	39.03	77.72
			Herbicide	0.93	9.87	-18.42	20.27
			Fire	25.73	9.83	6.47	44.99
			Mix	4.64	9.92	-14.80	24.08
		Medium	Control	85.38	9.87	66.04	104.72
			Herbicide	7.58	9.87	-11.76	26.92
			Fire	26.12	9.87	6.77	45.46
			Mix	3.86	9.87	-15.48	23.21
		Low	Control	103.25	9.87	83.91	122.59
			Herbicide	3.75	9.83	-15.51	23.01
			Fire	27.18	9.92	7.74	46.61
			Mix	6.35	9.87	-12.99	25.69
	2021	High	Control	67.87	9.87	48.53	87.22
			Herbicide	15.14	9.87	-4.21	34.48
			Fire	46.09	9.87	26.75	65.43
			Mix	17.71	9.87	-1.63	37.05
		Medium	Control	112.11	9.87	92.77	131.45
			Herbicide	39.31	9.87	19.98	58.65
			Fire	53.22	9.87	33.88	72.56
			Mix	26.49	9.87	7.15	45.83
		Low	Control	126.17	9.87	106.83	145.51
			Herbicide	37.95	9.87	18.61	57.29
			Fire	50.46	9.87	31.12	69.80
			Mix	26.81	9.87	7.47	46.15
Fire	2018	High	Fire	15.46	4.59	6.46	24.46
		Medium	Fire	13.86	4.42	5.20	22.52
		Low	Fire	14.83	4.42	6.17	23.49
	2019	High	Fire	22.67	4.59	13.67	31.67
		Medium	Fire	25.00	4.44	16.30	33.71
		Low	Fire	27.17	4.43	18.49	35.86
	2020	High	Fire	24.28	5.33	13.84	34.72
		Medium	Fire	28.28	5.35	17.78	38.77
		Low	Fire	26.05	5.40	15.46	36.65
	2021	High	Fire	44.92	5.38	34.38	55.46
		Medium	Fire	55.26	5.36	44.76	65.76
		Low	Fire	48.90	5.36	38.38	59.41
Thinning intensity	2017	High	Control	7.29	4.22	-0.98	15.57
		Medium	Control	7.15	4.23	-1.14	15.45
		Low	Control	6.79	4.23	-1.50	15.08

2018	High	Control	16.36	5.04	6.49	26.23
	Medium	Control	29.01	5.42	18.39	39.63
	Low	Control	22.23	5.42	11.61	32.84
2019	High	Control	27.61	5.04	17.74	37.48
	Medium	Control	37.81	5.36	27.31	48.30
	Low	Control	29.98	5.38	19.43	40.53
2020	High	Control	58.99	6.19	46.85	71.13
	Medium	Control	86.23	6.22	74.03	98.43
	Low	Control	102.84	6.23	90.64	115.04
2021	High	Control	68.65	6.19	56.51	80.79
	Medium	Control	113.77	6.23	101.57	125.98
	Low	Control	125.91	6.23	113.71	138.12

Table A5. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of woody coverage (%) for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	**Year**	**Basal Area**	**Treatment**	**β**	**SE**	**LCL**	**UCL**
All treatments	2020	High	Control	37.21	6.05	25.35	49.06
			Herbicide	1.97	6.05	-9.89	13.82
			Fire	21.43	6.01	9.64	33.21
			Mix	3.36	6.09	-8.58	15.30
		Medium	Control	42.17	6.04	30.32	54.01
			Herbicide	2.64	6.04	-9.21	14.48
			Fire	22.03	6.05	10.17	33.88
			Mix	9.67	6.05	-2.18	21.53
		Low	Control	37.60	6.05	25.75	49.45
			Herbicide	4.84	6.01	-6.94	16.63
			Fire	17.50	6.09	5.57	29.43
			Mix	2.47	6.05	-9.38	14.32
	2021	High	Control	64.30	6.05	52.44	76.16
			Herbicide	11.28	6.05	-0.58	23.13
			Fire	53.48	6.05	41.63	65.33
			Mix	16.10	6.05	4.24	27.95
		Medium	Control	72.37	6.04	60.52	84.21
			Herbicide	19.79	6.04	7.95	31.64
			Fire	40.97	6.05	29.12	52.83
			Mix	16.75	6.05	4.90	28.61
		Low	Control	61.46	6.05	49.60	73.31
			Herbicide	29.83	6.05	17.98	41.68
			Fire	43.30	6.05	31.45	55.15
			Mix	14.66	6.05	2.81	26.51
Fire	2018	High	Fire	18.32	4.18	10.13	26.52
		Medium	Fire	16.64	3.94	8.91	24.37
		Low	Fire	17.66	3.94	9.93	25.39
	2019	High	Fire	26.82	4.18	18.62	35.02
		Medium	Fire	27.21	3.96	19.45	34.98
		Low	Fire	28.94	3.95	21.19	36.68
	2020	High	Fire	19.86	4.75	10.55	29.18
		Medium	Fire	21.18	4.68	12.00	30.36
		Low	Fire	16.84	4.72	7.59	26.09
	2021	High	Fire	52.55	4.79	43.15	61.95
		Medium	Fire	40.05	4.70	30.84	49.25
		Low	Fire	42.53	4.71	33.31	51.76
Thinning intensity	2017	High	Control	11.79	2.29	7.30	16.27
		Medium	Control	8.94	2.30	4.43	13.45
		Low	Control	8.89	2.29	4.39	13.38

2018	High	Control	17.02	3.01	11.12	22.92
	Medium	Control	20.35	3.31	13.86	26.85
	Low	Control	21.49	3.31	15.00	27.98
2019	High	Control	25.86	3.01	19.96	31.76
	Medium	Control	30.02	3.26	23.63	36.42
	Low	Control	24.78	3.28	18.34	31.21
2020	High	Control	38.11	3.87	30.53	45.68
	Medium	Control	41.82	3.88	34.21	49.42
	Low	Control	39.12	3.88	31.52	46.73
2021	High	Control	65.30	3.87	57.72	72.88
	Medium	Control	71.25	3.89	63.63	78.88
	Low	Control	63.12	3.88	55.51	70.74

Table A6. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of grass genus richness (genera/ 20 m transect) for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	**Year**	**Basal Area**	**Treatment**	**β**	**SE**	**LCL**	**UCL**
All treatments	2020	High	Control	3.84	0.33	3.19	4.49
			Herbicide	1.52	0.33	0.87	2.17
			Fire	2.59	0.33	1.95	3.24
			Mix	2.55	0.33	1.89	3.20
		Medium	Control	3.04	0.33	2.39	3.69
			Herbicide	2.00	0.33	1.35	2.65
			Fire	4.00	0.33	3.35	4.65
			Mix	2.68	0.33	2.03	3.33
		Low	Control	2.96	0.33	2.31	3.61
			Herbicide	1.95	0.33	1.31	2.59
			Fire	4.36	0.33	3.70	5.01
			Mix	2.88	0.33	2.23	3.53
	2021	High	Control	3.12	0.33	2.47	3.77
			Herbicide	2.76	0.33	2.11	3.41
			Fire	3.24	0.33	2.59	3.89
			Mix	2.60	0.33	1.95	3.25
		Medium	Control	3.00	0.33	2.35	3.65
			Herbicide	3.72	0.33	3.07	4.37
			Fire	3.64	0.33	2.99	4.29
			Mix	3.08	0.33	2.43	3.73
		Low	Control	2.64	0.33	1.99	3.29
			Herbicide	3.56	0.33	2.91	4.21
			Fire	3.60	0.33	2.95	4.25
			Mix	2.92	0.33	2.27	3.57
Fire	2018	High	Fire	3.98	0.34	3.32	4.64
		Medium	Fire	4.18	0.33	3.54	4.82
		Low	Fire	4.36	0.33	3.71	5.00
	2019	High	Fire	4.18	0.34	3.52	4.84
		Medium	Fire	4.02	0.33	3.37	4.66
		Low	Fire	4.18	0.33	3.54	4.83
	2020	High	Fire	2.57	0.38	1.82	3.32
		Medium	Fire	3.99	0.39	3.23	4.75
		Low	Fire	4.35	0.39	3.58	5.12
	2021	High	Fire	3.23	0.39	2.47	3.99
		Medium	Fire	3.63	0.39	2.87	4.39
		Low	Fire	3.60	0.39	2.84	4.36
Thinning intensity	2017	High	Control	3.67	0.29	3.09	4.25
		Medium	Control	3.89	0.30	3.32	4.47
		Low	Control	3.68	0.29	3.10	4.26

2018	High	Control	4.11	0.34	3.44	4.79
	Medium	Control	4.34	0.36	3.63	5.05
	Low	Control	4.09	0.36	3.38	4.81
2019	High	Control	3.89	0.34	3.22	4.57
	Medium	Control	4.23	0.36	3.53	4.94
	Low	Control	4.07	0.36	3.36	4.79
2020	High	Control	3.67	0.40	2.88	4.46
	Medium	Control	3.51	0.40	2.72	4.30
	Low	Control	3.23	0.40	2.43	4.02
2021	High	Control	2.95	0.40	2.16	3.74
	Medium	Control	3.47	0.40	2.68	4.26
	Low	Control	2.91	0.40	2.11	3.70

Table A7. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of forb genus richness (genera/ 20 m transect) for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	5.00	0.72	3.59	6.41
			Herbicide	3.56	0.72	2.15	4.97
			Fire	7.20	0.72	5.79	8.60
			Mix	7.80	0.73	6.37	9.22
		Medium	Control	5.40	0.72	3.99	6.81
			Herbicide	5.76	0.72	4.35	7.17
			Fire	9.20	0.72	7.79	10.61
			Mix	7.96	0.72	6.55	9.37
		Low	Control	4.64	0.72	3.23	6.05
			Herbicide	6.43	0.72	5.03	7.84
			Fire	9.74	0.73	8.32	11.17
			Mix	8.16	0.72	6.75	9.57
	2021	High	Control	3.04	0.72	1.63	4.45
			Herbicide	5.28	0.72	3.87	6.69
			Fire	6.36	0.72	4.95	7.77
			Mix	7.08	0.72	5.67	8.49
		Medium	Control	3.92	0.72	2.51	5.33
			Herbicide	8.32	0.72	6.91	9.73
			Fire	8.84	0.72	7.43	10.25
			Mix	9.36	0.72	7.95	10.77
		Low	Control	4.36	0.72	2.95	5.77
			Herbicide	7.32	0.72	5.91	8.73
			Fire	8.60	0.72	7.19	10.01
			Mix	10.36	0.72	8.95	11.77
Fire	2018	High	Fire	7.40	0.54	6.34	8.47
		Medium	Fire	10.04	0.52	9.02	11.06
		Low	Fire	9.75	0.52	8.73	10.76
	2019	High	Fire	4.94	0.54	3,88	6.01
		Medium	Fire	7.38	0.52	6.35	8.41
		Low	Fire	7.70	0.52	6.67	8.72
	2020	High	Fire	7.04	0.66	5.75	8.33
		Medium	Fire	9.19	0.67	7.88	10.49
		Low	Fire	9.74	0.67	8.42	11.06
	2021	High	Fire	6.22	0.67	4.91	7.53
		Medium	Fire	8.83	0.67	7.52	10.13
		Low	Fire	8.60	0.67	7.30	9.90
Thinning intensity	2017	High	Control	5.16	0.45	4.27	6.05
		Medium	Control	6.92	0.46	6.03	7.81
		Low	Control	6.05	0.45	5.16	6.94

2018	High	Control	6.62	0.55	5.54	7.70
	Medium	Control	9.00	0.59	7.85	10.16
	Low	Control	8.33	0.59	7.17	9.48
2019	High	Control	4.78	0.55	3.70	5.86
	Medium	Control	7.09	0.58	5.95	8.23
	Low	Control	6.35	0.59	5.20	7.50
2020	High	Control	4.78	0.67	3.47	6.08
	Medium	Control	5.44	0.67	4.12	6.75
	Low	Control	5.38	0.67	4.07	6.70
2021	High	Control	2.82	0.67	1.51	4.12
	Medium	Control	3.96	0.67	2.64	5.27
	Low	Control	5.10	0.67	3.79	6.42

Table A8. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of vine genus richness (genera/ 20 m transect) for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	4.68	0.35	4.00	5.36
			Herbicide	1.44	0.35	0.76	2.12
			Fire	3.40	0.34	2.73	4.08
			Mix	1.82	0.35	1.13	2.51
		Medium	Control	4.64	0.35	3.96	5.32
			Herbicide	2.64	0.35	1.96	3.32
			Fire	4.20	0.35	3.52	4.88
			Mix	1.48	0.35	0.80	2.16
		Low	Control	5.32	0.35	4.64	6.00
			Herbicide	2.06	0.34	1.39	2.74
			Fire	3.36	0.35	2.67	4.05
			Mix	1.88	0.35	1.20	2.56
	2021	High	Control	4.92	0.35	4.24	5.60
			Herbicide	3.76	0.35	3.08	4.44
			Fire	4.36	0.35	3.68	5.04
			Mix	2.60	0.35	1.92	3.28
		Medium	Control	4.88	0.35	4.20	5.56
			Herbicide	3.52	0.35	2.84	4.20
			Fire	4.32	0.35	3.64	5.00
			Mix	2.72	0.35	2.04	3.40
		Low	Control	4.76	0.35	4.08	5.44
			Herbicide	3.12	0.35	2.44	3.80
			Fire	4.16	0.35	3.48	4.84
			Mix	3.08	0.35	2.40	3.76
Fire	2018	High	Fire	4.30	0.36	3.59	5.01
		Medium	Fire	4.31	0.33	3.65	4.96
		Low	Fire	3.92	0.33	3.27	4.57
	2019	High	Fire	4.32	0.36	3.61	5.03
		Medium	Fire	4.41	0.34	3.75	5.07
		Low	Fire	4.20	0.34	3.54	4.86
	2020	High	Fire	3.40	0.40	2.61	4.19
		Medium	Fire	4.47	0.39	3.71	5.23
		Low	Fire	3.15	0.39	2.38	3.92
	2021	High	Fire	4.36	0.41	3.57	5.16
		Medium	Fire	4.59	0.39	3.83	5.35
		Low	Fire	3.95	0.39	3.19	4.71
Thinning intensity	2017	High	Control	3.93	0.23	3.48	4.38
		Medium	Control	3.78	0.23	3.33	4.23
		Low	Control	3.67	0.23	3.22	4.12

2018	High	Control	4.48	0.27	3.95	5.01
	Medium	Control	4.65	0.29	4.09	5.21
	Low	Control	4.40	0.29	3.83	4.96
2019	High	Control	4.40	0.27	3.87	4.93
	Medium	Control	4.59	0.28	4.04	5.15
	Low	Control	4.69	0.29	4.13	5.25
2020	High	Control	4.68	0.33	4.04	5.32
	Medium	Control	4.64	0.33	4.00	5.28
	Low	Control	5.37	0.33	4.73	6.02
2021	High	Control	4.92	0.33	4.28	5.56
	Medium	Control	4.88	0.33	4.24	5.52
	Low	Control	4.81	0.33	4.17	5.46

Table A9. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of woody genus richness (genera/ 20 m transect) for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	**Year**	**Basal Area**	**Treatment**	**β**	**SE**	**LCL**	**UCL**
All treatments	2020	High	Control	6.04	0.43	5.20	6.88
			Herbicide	1.72	0.43	0.88	2.56
			Fire	3.68	0.42	2.85	4.50
			Mix	2.27	0.43	1.42	3.11
		Medium	Control	6.04	0.43	5.20	6.88
			Herbicide	2.20	0.43	1.36	3.04
			Fire	4.80	0.43	3.96	5.64
			Mix	1.40	0.43	0.56	2.24
		Low	Control	5.60	0.43	4.76	6.44
			Herbicide	2.03	0.42	1.20	2.86
			Fire	3.27	0.43	2.43	4.12
			Mix	1.36	0.43	0.52	2.20
	2021	High	Control	6.20	0.43	5.36	7.04
			Herbicide	3.36	0.43	2.52	4.20
			Fire	5.48	0.43	4.64	6.32
			Mix	3.48	0.43	2.64	4.32
		Medium	Control	7.00	0.43	6.16	7.84
			Herbicide	3.48	0.43	2.64	4.32
			Fire	6.20	0.43	5.36	7.04
			Mix	3.80	0.43	2.96	4.64
		Low	Control	5.40	0.43	4.56	6.24
			Herbicide	3.60	0.43	2.76	4.44
			Fire	5.52	0.43	4.68	6.36
			Mix	3.64	0.43	2.80	4.48
Fire	2018	High	Fire	4.29	0.40	3.50	5.08
		Medium	Fire	4.79	0.37	4.07	5.51
		Low	Fire	4.22	0.37	3.50	4.94
	2019	High	Fire	5.07	0.40	4.28	5.86
		Medium	Fire	4.80	0.37	4.07	5.53
		Low	Fire	4.60	0.37	3.87	5.33
	2020	High	Fire	3.62	0.48	2.67	4.57
		Medium	Fire	4.89	0.48	3.96	5.82
		Low	Fire	3.15	0.48	2.20	4.09
	2021	High	Fire	5.44	0.49	4.48	6.40
		Medium	Fire	6.29	0.48	5.36	7.22
		Low	Fire	5.39	0.48	4.46	6.32
Thinning intensity	2017	High	Control	4.31	0.27	3.79	4.84
		Medium	Control	4.34	0.27	3.81	4.87
		Low	Control	3.85	0.27	3.33	4.38

2018	High	Control	4.93	0.33	4.28	5.57
	Medium	Control	5.58	0.36	4.88	6.28
	Low	Control	4.78	0.36	4.08	5.48
2019	High	Control	5.33	0.33	4.68	5.97
	Medium	Control	5.30	0.35	4.61	5.99
	Low	Control	4.74	0.36	4.04	5.44
2020	High	Control	6.09	0.42	5.27	6.91
	Medium	Control	6.06	0.42	5.24	6.88
	Low	Control	5.68	0.42	4.86	6.51
2021	High	Control	6.25	0.42	5.43	7.07
	Medium	Control	7.02	0.42	6.20	7.84
	Low	Control	5.48	0.42	4.66	6.31

Table A10. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of visual obstruction (%) 0.0–0.5 m in height for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	93.72	4.68	84.54	102.89
			Herbicide	27.51	4.68	18.34	36.68
			Fire	68.71	4.68	59.53	77.88
			Mix	31.86	4.68	22.69	41.03
		Medium	Control	95.60	4.68	86.43	104.77
			Herbicide	47.69	4.68	38.52	56.86
			Fire	84.83	4.65	75.72	93.93
			Mix	48.24	4.72	38.99	57.50
		Low	Control	98.29	4.68	89.11	107.46
			Herbicide	54.79	4.68	45.62	63.96
			Fire	90.14	5.04	80.26	100.01
			Mix	56.41	4.56	47.48	65.34
	2021	High	Control	90.20	4.68	81.03	99.37
			Herbicide	57.39	4.68	48.22	66.57
			Fire	95.41	4.68	86.24	104.58
			Mix	77.03	4.68	67.85	86.20
		Medium	Control	97.50	4.68	88.32	106.67
			Herbicide	75.85	4.68	66.68	85.03
			Fire	96.31	4.68	87.14	105.48
			Mix	83.66	4.68	74.49	92.83
		Low	Control	98.20	4.68	89.02	107.37
			Herbicide	85.06	4.68	75.88	94.23
			Fire	97.46	4.68	88.29	106.63
			Mix	90.70	4.68	81.53	99.87
Fire	2018	High	Fire	82.31	3.26	75.91	88.71
		Medium	Fire	87.45	3.03	81.50	93.39
		Low	Fire	89.68	3.05	83.69	95.66
	2019	High	Fire	82.83	3.26	76.43	89.22
		Medium	Fire	88.64	3.05	82.66	94.63
		Low	Fire	89.06	3.15	82.88	95.23
	2020	High	Fire	69.43	3.82	61.94	76.92
		Medium	Fire	86.93	3.69	79.70	94.15
		Low	Fire	88.72	3.98	80.93	96.51
	2021	High	Fire	96.14	3.82	88.65	103.62
		Medium	Fire	98.56	3.72	91.27	105.85
		Low	Fire	96.70	3.75	89.35	104.04
Thinning intensity	2017	High	Control	61.66	3.23	55.33	67.98
		Medium	Control	62.63	3.23	56.30	68.95
		Low	Control	60.18	3.24	53.83	66.53

2018	High	Control	83.95	3.71	76.67	91.23
	Medium	Control	92.76	3.91	85.10	100.41
	Low	Control	88.68	3.91	81.01	96.34
2019	High	Control	79.72	3.71	72.44	87.00
	Medium	Control	90.67	3.91	83.02	98.33
	Low	Control	91.63	3.81	84.17	99.08
2020	High	Control	95.58	4.30	87.15	104.01
	Medium	Control	98.17	4.31	89.72	106.61
	Low	Control	99.02	4.31	90.57	107.47
2021	High	Control	92.07	4.30	83.64	100.50
	Medium	Control	100.00	4.31	91.61	108.51
	Low	Control	98.93	4.31	90.48	107.38

Table A11. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of visual obstruction (%) 0.5–1.0 m in height for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	66.16	6.59	53.24	79.08
			Herbicide	12.23	6.59	-0.69	25.15
			Fire	40.16	6.59	27.24	53.07
			Mix	10.61	6.59	-2.31	23.53
		Medium	Control	83.11	6.59	70.19	96.03
			Herbicide	21.31	6.59	8.39	34.22
			Fire	41.91	6.55	29.06	54.76
			Mix	15.22	6.64	2.21	28.23
		Low	Control	88.85	6.59	75.93	101.77
			Herbicide	30.92	6.59	18.01	43.84
			Fire	49.37	7.01	35.63	63.11
			Mix	21.21	6.46	8.56	33.86
	2021	High	Control	67.54	6.59	54.62	80.45
			Herbicide	21.10	6.59	8.18	34.01
			Fire	77.27	6.59	64.35	90.19
			Mix	43.34	6.59	30.42	56.25
		Medium	Control	87.95	6.59	75.03	100.87
			Herbicide	41.82	6.59	28.90	54.74
			Fire	74.26	6.59	61.34	87.17
			Mix	53.16	6.59	40.24	66.08
		Low	Control	91.21	6.59	78.30	104.13
			Herbicide	59.67	6.59	46.75	72.59
			Fire	84.17	6.59	71.26	97.09
			Mix	56.80	6.59	43.88	69.72
Fire	2018	High	Fire	65.57	5.41	54.96	76.18
		Medium	Fire	73.23	4.95	63.53	82.92
		Low	Fire	74.15	4.99	64.37	83.93
	2019	High	Fire	61.20	5.41	50.59	71.81
		Medium	Fire	65.85	4.98	56.09	75.61
		Low	Fire	63.21	5.14	53.14	73.28
	2020	High	Fire	41.22	6.27	28.93	53.51
		Medium	Fire	43.89	5.98	32.17	55.61
		Low	Fire	47.05	6.43	34.44	59.66
	2021	High	Fire	78.33	6.27	66.04	90.63
		Medium	Fire	76.53	6.03	64.72	88.35
		Low	Fire	82.55	6.09	70.61	94.48
Thinning intensity	2017	High	Control	40.91	3.73	33.59	48.22
		Medium	Control	36.68	3.73	29.37	43.99
		Low	Control	31.95	3.74	24.61	39.29

2018	High	Control	68.12	4.50	59.29	76.94
	Medium	Control	80.02	4.79	70.62	89.41
	Low	Control	72.74	4.80	63.34	82.14
2019	High	Control	53.01	4.50	44.19	61.83
	Medium	Control	68.64	4.79	59.25	78.04
	Low	Control	74.78	4.64	65.69	83.86
2020	High	Control	67.90	5.37	57.37	78.43
	Medium	Control	82.85	5.38	72.30	93.40
	Low	Control	90.23	5.38	79.68	100.78
2021	High	Control	69.27	5.37	58.74	79.80
	Medium	Control	87.69	5.38	77.14	98.24
	Low	Control	92.60	5.38	82.05	103.15

Table A12. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of visual obstruction (%) 1.0–2.5 m in height for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	**Year**	**Basal Area**	**Treatment**	**β**	**SE**	**LCL**	**UCL**
All treatments	2020	High	Control	54.77	5.15	44.68	64.87
			Herbicide	5.82	5.15	-4.28	15.91
			Fire	15.90	5.15	5.80	26.00
			Mix	3.74	5.15	-6.36	13.83
		Medium	Control	74.18	5.15	64.08	84.27
			Herbicide	9.23	5.15	-0.87	19.32
			Fire	23.20	5.11	13.18	33.23
			Mix	1.89	5.20	-8.29	12.07
		Low	Control	78.86	5.15	68.76	88.95
			Herbicide	10.13	5.15	0.04	20.23
			Fire	19.62	5.54	8.77	30.48
			Mix	6.83	5.02	-3.00	16.67
	2021	High	Control	52.36	5.15	42.27	62.46
			Herbicide	12.24	5.15	2.14	22.33
			Fire	54.52	5.15	44.42	64.61
			Mix	21.71	5.15	11.62	31.81
		Medium	Control	79.92	5.15	69.82	90.01
			Herbicide	26.44	5.15	16.34	36.54
			Fire	48.53	5.15	38.43	58.62
			Mix	28.89	5.15	18.80	38.99
		Low	Control	82.60	5.15	72.50	92.69
			Herbicide	41.75	5.15	31.66	51.85
			Fire	51.68	5.15	41.58	61.77
			Mix	26.28	5.15	16.18	36.37
Fire	2018	High	Fire	44.71	4.83	35.25	54.18
		Medium	Fire	47.31	4.46	38.57	56.04
		Low	Fire	46.70	4.50	37.88	55.52
	2019	High	Fire	41.02	4.83	31.56	50.49
		Medium	Fire	47.01	4.50	38.19	55.82
		Low	Fire	42.82	4.68	33.65	51.98
	2020	High	Fire	16.90	5.87	5.40	28.40
		Medium	Fire	24.97	5.68	13.84	36.10
		Low	Fire	17.88	6.20	5.72	30.03
	2021	High	Fire	55.52	5.87	44.02	67.02
		Medium	Fire	50.47	5.74	39.22	61.72
		Low	Fire	50.50	5.79	39.15	61.84
Thinning intensity	2017	High	Control	26.01	2.40	21.32	30.71
		Medium	Control	18.98	2.40	14.29	23.68
		Low	Control	16.57	2.41	11.84	21.29

2018	High	Control	47.59	3.22	41.28	53.91
	Medium	Control	60.90	3.54	53.96	67.83
	Low	Control	50.76	3.54	43.83	57.70
2019	High	Control	43.99	3.22	37.67	50.31
	Medium	Control	52.69	3.54	45.76	59.63
	Low	Control	62.98	3.34	56.42	69.53
2020	High	Control	55.77	4.21	47.52	64.03
	Medium	Control	73.98	4.22	65.71	82.24
	Low	Control	80.02	4.22	71.76	88.29
2021	High	Control	53.37	4.21	45.11	61.62
	Medium	Control	79.71	4.22	71.45	87.98
	Low	Control	83.77	4.22	75.50	92.03

Table A13. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of visual obstruction (%) 0.0–2.5 m in height for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	64.84	4.89	55.26	74.42
			Herbicide	11.44	4.89	1.86	21.02
			Fire	31.31	4.89	21.73	40.89
			Mix	10.74	4.89	1.16	20.31
		Medium	Control	80.25	4.89	70.67	89.83
			Herbicide	19.33	4.89	9.76	28.91
			Fire	39.29	4.86	29.77	48.81
			Mix	13.83	4.92	4.18	23.47
		Low	Control	84.74	4.89	75.16	94.32
			Herbicide	23.22	4.89	13.65	32.80
			Fire	39.64	5.20	29.44	49.83
			Mix	19.58	4.78	10.21	28.95
	2021	High	Control	62.97	4.89	53.39	72.54
			Herbicide	23.04	4.89	13.46	32.62
			Fire	67.25	4.89	57.67	76.82
			Mix	37.10	4.89	27.52	46.68
		Medium	Control	85.04	4.89	75.46	94.62
			Herbicide	39.40	4.89	29.82	48.98
			Fire	63.23	4.89	53.65	72.81
			Mix	44.70	4.89	35.12	54.28
		Low	Control	87.44	4.89	77.86	97.02
			Herbicide	54.00	4.89	44.42	63.57
			Fire	67.33	4.89	57.76	76.91
			Mix	45.27	4.89	35.69	54.84
Fire	2018	High	Fire	56.40	4.45	47.69	65.12
		Medium	Fire	60.58	4.11	52.53	68.63
		Low	Fire	60.84	4.14	52.72	68.96
	2019	High	Fire	53.42	4.45	44.70	62.14
		Medium	Fire	59.18	4.14	51.07	67.29
		Low	Fire	56.20	4.28	47.81	64.59
	2020	High	Fire	32.37	5.24	22.10	42.63
		Medium	Fire	41.36	5.04	31.48	51.23
		Low	Fire	37.86	5.44	27.19	48.54
	2021	High	Fire	68.30	5.24	58.03	78.56
		Medium	Fire	65.50	5.08	55.54	75.47
		Low	Fire	66.15	5.14	56.08	76.22
Thinning intensity	2017	High	Control	36.12	2.40	31.42	40.83
		Medium	Control	31.25	2.40	26.55	35.96
		Low	Control	28.39	2.42	23.66	33.12

2018	High	Control	59.09	3.10	53.02	65.16
	Medium	Control	71.28	3.36	64.70	77.87
	Low	Control	63.02	3.36	56.43	69.61
2019	High	Control	53.06	3.10	46.99	59.12
	Medium	Control	63.67	3.36	57.09	70.25
	Low	Control	71.33	3.21	65.04	77.62
2020	High	Control	66.28	3.90	58.64	73.92
	Medium	Control	80.49	3.91	72.83	88.15
	Low	Control	85.98	3.91	78.33	93.64
2021	High	Control	64.41	3.90	56.77	72.05
	Medium	Control	85.28	3.91	77.62	92.94
	Low	Control	88.68	3.91	81.03	96.34

Table A14. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of woody stem density (stems/m^2) <1 m in height for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	0.89	0.16	0.58	1.21
			Herbicide	0.06	0.16	-0.25	0.38
			Fire	0.68	0.16	0.37	1.00
			Mix	0.21	0.16	-0.11	0.53
		Medium	Control	0.62	0.16	0.30	0.93
			Herbicide	0.09	0.16	-0.23	0.41
			Fire	1.23	0.16	0.91	1.55
			Mix	0.15	0.16	-0.17	0.47
		Low	Control	0.86	0.16	0.54	1.17
			Herbicide	0.22	0.16	-0.09	0.54
			Fire	1.05	0.16	0.73	1.37
			Mix	0.19	0.16	-0.13	0.50
	2021	High	Control	0.78	0.16	0.46	1.10
			Herbicide	0.50	0.16	0.18	0.82
			Fire	0.88	0.16	0.57	1.20
			Mix	0.41	0.16	0.09	0.73
		Medium	Control	0.54	0.16	0.22	0.86
			Herbicide	0.30	0.16	-0.01	0.62
			Fire	1.20	0.16	0.89	1.52
			Mix	0.59	0.16	0.27	0.91
		Low	Control	0.49	0.16	0.17	0.81
			Herbicide	0.59	0.16	0.27	0.91
			Fire	1.07	0.16	0.75	1.39
			Mix	0.59	0.16	0.27	0.91
Fire	2018	High	Fire	0.77	0.17	0.44	1.10
		Medium	Fire	0.68	0.16	0.36	1.00
		Low	Fire	0.97	0.16	0.65	1.29
	2019	High	Fire	1.23	0.17	0.90	1.57
		Medium	Fire	1.01	0.16	0.69	1.33
		Low	Fire	1.15	0.16	0.83	1.47
	2020	High	Fire	0.69	0.21	0.29	1.10
		Medium	Fire	1.24	0.21	0.83	1.66
		Low	Fire	1.06	0.21	0.65	1.47
	2021	High	Fire	0.90	0.21	0.49	1.31
		Medium	Fire	1.22	0.21	0.81	1.64
		Low	Fire	1.08	0.21	0.67	1.49
Thinning intensity	2017	High	Control	0.54	0.19	0.16	0.91
		Medium	Control	0.50	0.19	0.12	0.87
		Low	Control	0.68	0.19	0.31	1.05

2018	High	Control	0.63	0.26	0.13	1.13
	Medium	Control	0.70	0.28	0.15	1.26
	Low	Control	0.58	0.28	0.02	1.13
2019	High	Control	1.80	0.26	1.30	2.30
	Medium	Control	0.75	0.28	0.20	1.30
	Low	Control	0.81	0.28	0.26	1.37
2020	High	Control	0.89	0.35	0.20	1.58
	Medium	Control	0.63	0.35	-0.06	1.32
	Low	Control	0.86	0.35	0.17	1.55
2021	High	Control	0.78	0.35	0.09	1.47
	Medium	Control	0.54	0.35	-0.15	1.23
	Low	Control	0.49	0.35	-0.20	1.18

Table A15. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of woody stem density (stems/m^2) ≥1 m in height for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	0.44	0.23	-0.01	0.89
			Herbicide	0.02	0.23	-0.43	0.47
			Fire	0.08	0.23	-0.37	0.53
			Mix	0.00	0.23	-0.46	0.45
		Medium	Control	1.32	0.23	0.87	1.77
			Herbicide	0.04	0.23	-0.41	0.49
			Fire	0.06	0.23	-0.39	0.51
			Mix	0.00	0.23	-0.45	0.45
		Low	Control	1.46	0.23	1.01	1.91
			Herbicide	0.00	0.23	-0.45	0.45
			Fire	0.10	0.23	-0.35	0.55
			Mix	0.00	0.23	-0.45	0.45
	2021	High	Control	0.40	0.23	-0.05	0.85
			Herbicide	0.04	0.23	-0.41	0.49
			Fire	0.88	0.23	0.43	1.33
			Mix	0.10	0.23	-0.35	0.55
		Medium	Control	0.84	0.23	0.39	1.30
			Herbicide	0.16	0.23	-0.29	0.61
			Fire	0.30	0.23	-0.15	0.75
			Mix	0.12	0.23	-0.33	0.57
		Low	Control	1.24	0.23	0.79	1.69
			Herbicide	0.06	0.23	-0.39	0.51
			Fire	0.44	0.23	-0.01	0.89
			Mix	0.08	0.23	-0.37	0.53
Fire	2018	High	Fire	0.22	0.14	-0.05	0.49
		Medium	Fire	0.18	0.13	-0.06	0.43
		Low	Fire	0.19	0.13	-0.06	0.44
	2019	High	Fire	0.59	0.14	0.32	0.86
		Medium	Fire	0.46	0.13	0.21	0.71
		Low	Fire	0.63	0.13	0.39	0.88
	2020	High	Fire	0.08	0.18	-0.28	0.43
		Medium	Fire	0.06	0.18	-0.30	0.42
		Low	Fire	0.10	0.18	-0.27	0.46
	2021	High	Fire	0.88	0.18	0.52	1.24
		Medium	Fire	0.30	0.18	-0.06	0.66
		Low	Fire	0.43	0.18	0.07	0.80
Thinning intensity	2017	High	Control	0.20	0.13	-0.05	0.46
		Medium	Control	0.14	0.13	-0.11	0.40
		Low	Control	0.10	0.13	-0.16	0.36

2018	High	Control	0.20	0.15	-0.09	0.49
	Medium	Control	0.26	0.16	-0.05	0.57
	Low	Control	0.43	0.16	0.13	0.74
2019	High	Control	0.27	0.15	-0.02	0.56
	Medium	Control	0.46	0.16	0.16	0.77
	Low	Control	0.50	0.16	0.19	0.80
2020	High	Control	0.45	0.18	0.11	0.80
	Medium	Control	1.33	0.18	0.98	1.67
	Low	Control	1.47	0.18	1.13	1.81
2021	High	Control	0.41	0.18	0.06	0.75
	Medium	Control	0.85	0.18	0.50	1.19
	Low	Control	1.25	0.18	0.91	1.59

Table A16. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of *Rubus* stem density (stems/m^2) ≥1 m in height for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	Year	Basal Area	Treatment	β	SE	LCL	UCL
All treatments	2020	High	Control	0.68	0.46	-0.23	1.59
			Herbicide	0.00	0.46	-0.91	0.91
			Fire	0.07	0.46	-0.83	0.98
			Mix	0.00	0.47	-0.91	0.91
		Medium	Control	1.90	0.46	0.99	2.81
			Herbicide	0.04	0.46	-0.87	0.95
			Fire	0.04	0.46	-0.87	0.94
			Mix	0.00	0.46	-0.90	0.91
		Low	Control	3.06	0.46	2.16	3.97
			Herbicide	0.00	0.46	-0.91	0.91
			Fire	0.01	0.46	-0.90	0.91
			Mix	0.00	0.46	-0.91	0.90
	2021	High	Control	0.48	0.46	-0.43	1.39
			Herbicide	0.04	0.46	-0.87	0.95
			Fire	0.84	0.46	-0.07	1.74
			Mix	0.26	0.46	-0.65	1.17
		Medium	Control	1.94	0.46	1.04	2.85
			Herbicide	0.48	0.46	-0.43	1.39
			Fire	0.34	0.46	-0.57	1.25
			Mix	0.44	0.46	-0.47	1.35
		Low	Control	2.36	0.46	1.45	3.27
			Herbicide	0.48	0.46	-0.43	1.39
			Fire	0.76	0.46	-0.15	1.67
			Mix	0.48	0.46	-0.43	1.39

Table A17. Mean estimates (β), standard errors (SE), lower confidence limits (LCL), and upper confidence limits (UCL) of canopy coverage (%) ≥1 m in height for mid-rotation loblolly pine (*Pinus taeda*) stands thinned to low (9 m^2 ha^{-1}), medium (14 m^2 ha^{-1}), or high (18 m^2 ha^{-1}) residual basal areas in 2017 and treated with two prescribed burns (spring 2018, 2020) and herbicide (imazapyr + metsulfuron methyl; fall 2019), or a combination thereof (herbicide + fire; mix) in Greene and Hancock counties, GA.

Model	**Year**	**Basal Area**	**Treatment**	**β**	**SE**	**LCL**	**UCL**
All treatments	2020	High	Control	86.10	3.09	80.06	92.15
			Herbicide	84.58	3.09	78.54	90.63
			Fire	84.02	3.09	77.97	90.07
			Mix	84.40	3.09	78.35	90.44
		Medium	Control	82.31	3.09	76.27	88.36
			Herbicide	76.25	3.09	70.20	82.30
			Fire	72.58	3.09	66.54	78.63
			Mix	69.94	3.31	63.46	76.42
		Low	Control	76.52	3.14	70.36	82.68
			Herbicide	70.96	3.09	64.91	77.01
			Fire	69.68	3.01	63.79	75.57
			Mix	69.97	3.05	63.99	75.94
	2021	High	Control	92.94	3.09	86.89	98.98
			Herbicide	91.85	3.09	85.81	97.90
			Fire	84.58	3.09	78.54	90.63
			Mix	89.31	3.09	83.27	95.36
		Medium	Control	90.77	3.09	84.72	96.82
			Herbicide	81.02	3.09	74.97	87.07
			Fire	77.77	3.09	71.72	83.82
			Mix	78.71	3.09	72.66	84.76
		Low	Control	85.63	3.09	79.58	91.67
			Herbicide	72.33	3.09	66.29	78.38
			Fire	73.79	3.09	67.74	79.84
			Mix	71.29	3.09	65.24	77.34